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Kobayashi et al.

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(54) **ROTARY PHASE CONTROLLER, AND VALVE TIMING CONTROLLER OF INTERNAL COMBUSTION ENGINE**

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(22) Filed: **Jun. 4, 2002**

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Oct. 22, 2001 (JP) 2001-323941

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(52) **U.S. Cl.** **123/90.17**; 123/90.11; 123/90.15; 123/90.16; 123/90.27; 123/90.31; 251/129.01; 464/29
(58) **Field of Search** .... 123/90.11, 90.15, 123/90.16, 90.17, 90.27, 90.31; 251/129.01, 129.16, 129.15; 464/1, 2, 160, 29; 74/568 R

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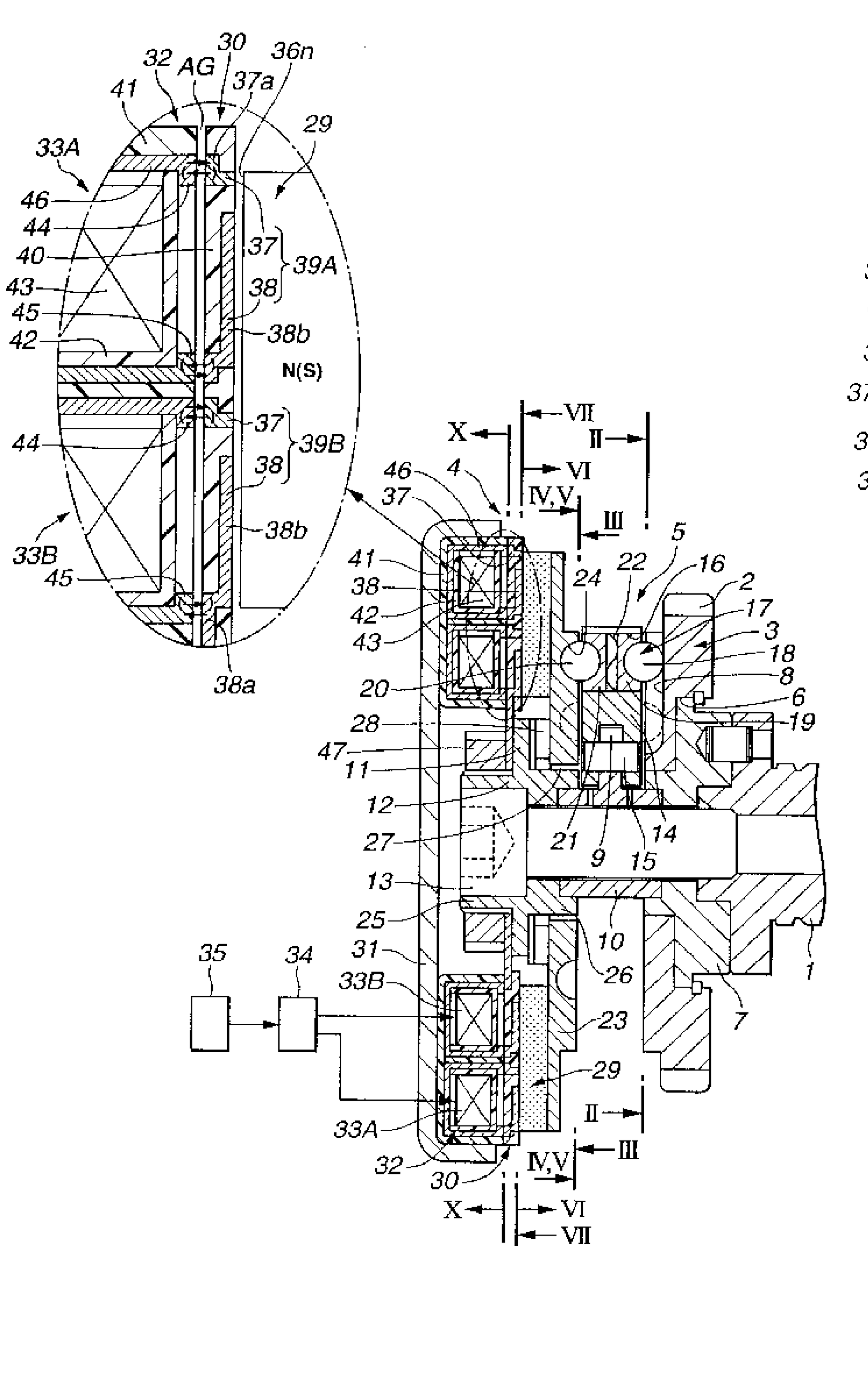
Assistant Examiner—Ching Chang
(74) *Attorney, Agent, or Firm*—Foley & Lardner

(57) **ABSTRACT**

A rotary phase controller includes: a permanent magnet block, a yoke block, and an electromagnetic coil block. The permanent magnet block has a constitution where different magnetic pole surfaces are alternately arranged. The yoke block includes yokes. The yoke includes: a first pole tooth ring formed with first pole teeth opposing the magnetic pole surfaces, and a second pole tooth ring formed with second pole teeth opposing the magnetic pole surfaces. The first pole teeth and the second pole teeth are alternately disposed. The first pole teeth of the first yoke are shifted by a predetermined pitch circumferentially from the second pole teeth of the second yoke. The electromagnetic coil block includes electromagnetic coils. A first electromagnetic coil and a second electromagnetic coil have a magnetic input-output end opposing, via air gap, the first pole tooth ring and the second pole tooth ring of the first yoke and second yoke.

15 Claims, 12 Drawing Sheets



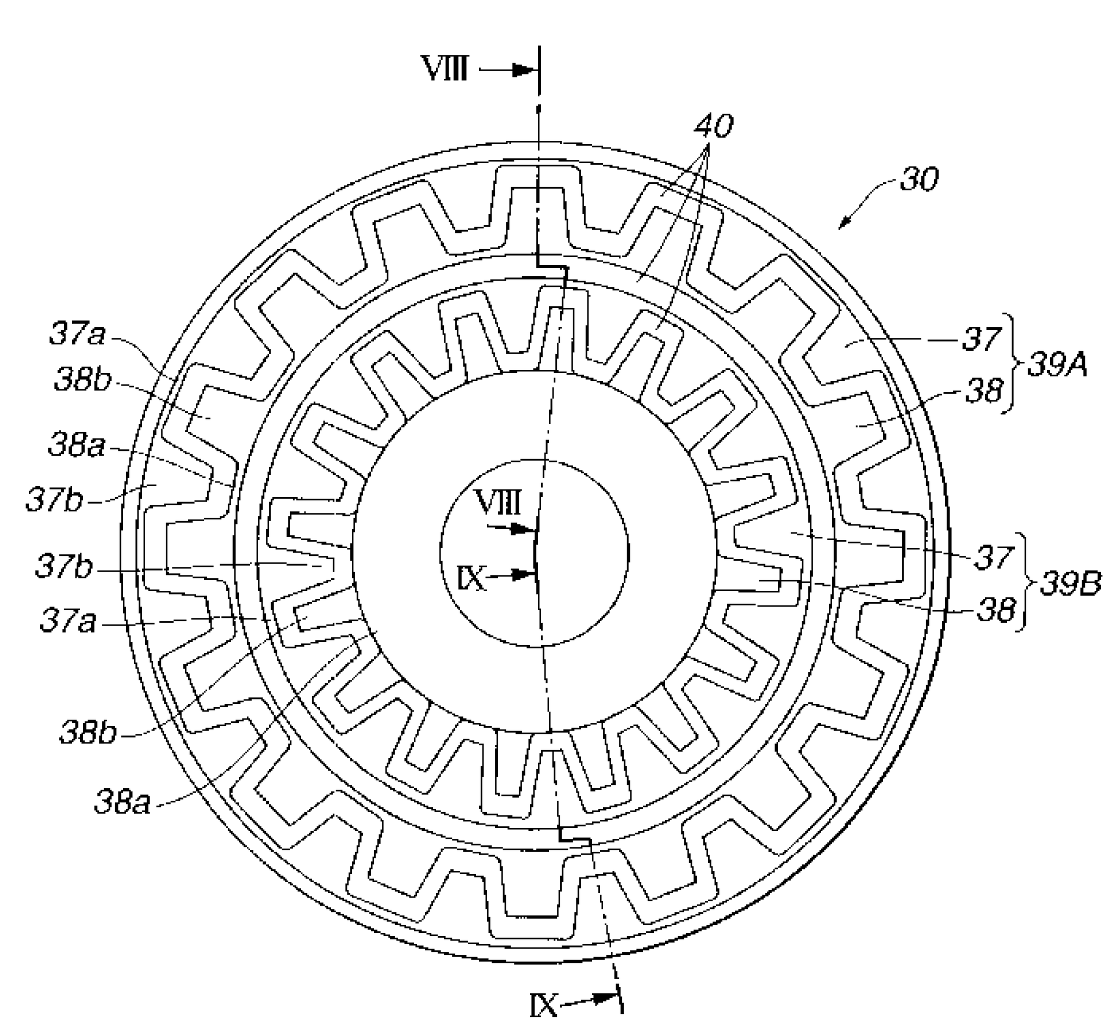


FIG. 1B

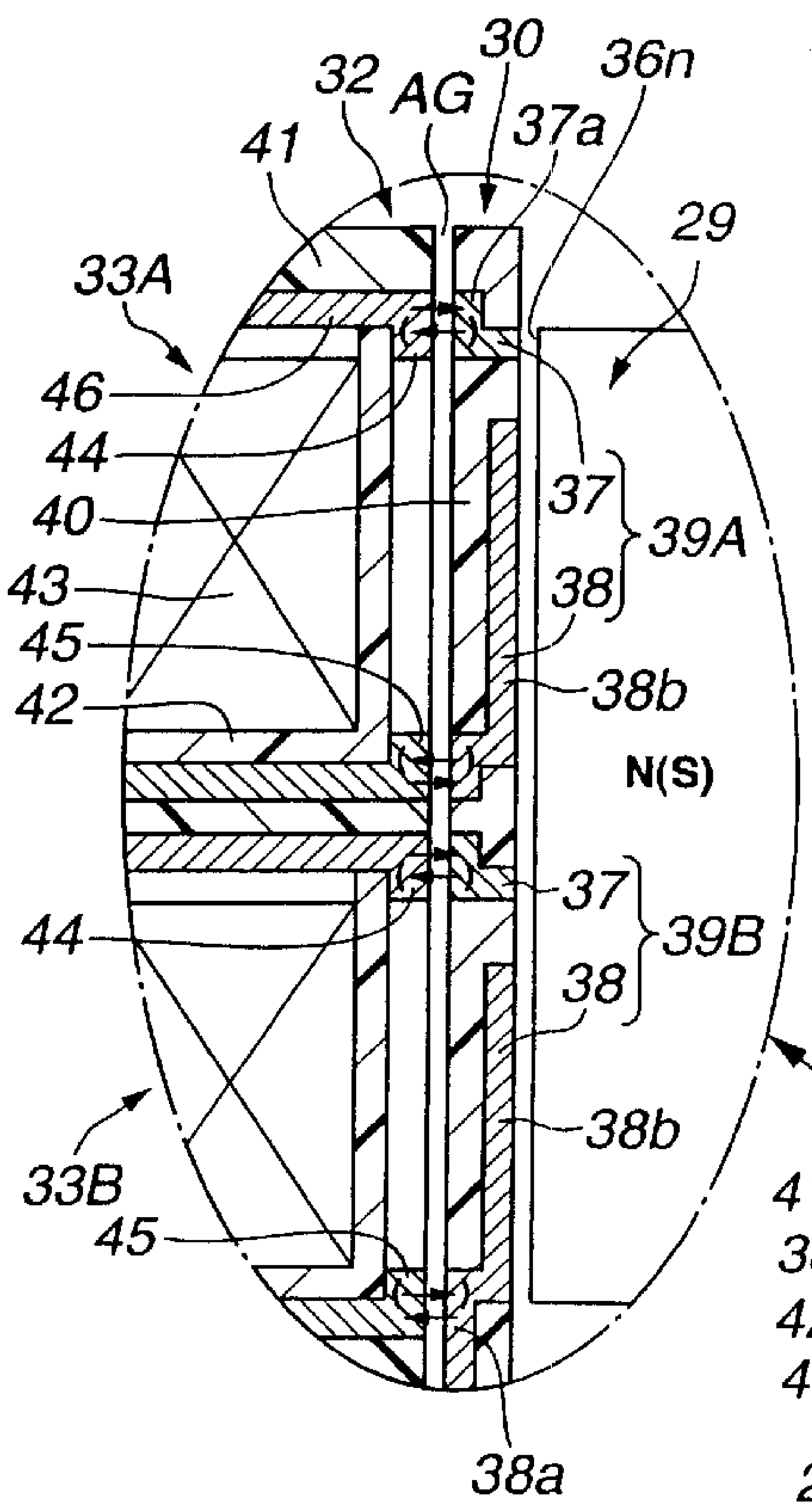

30
32
AG
36n
37a
41
29
33A
46
44
40
37
39A
43
38
45
42
38b
N(S)
37
39B
44
38
33B
38b
45
38a

FIG. 1A

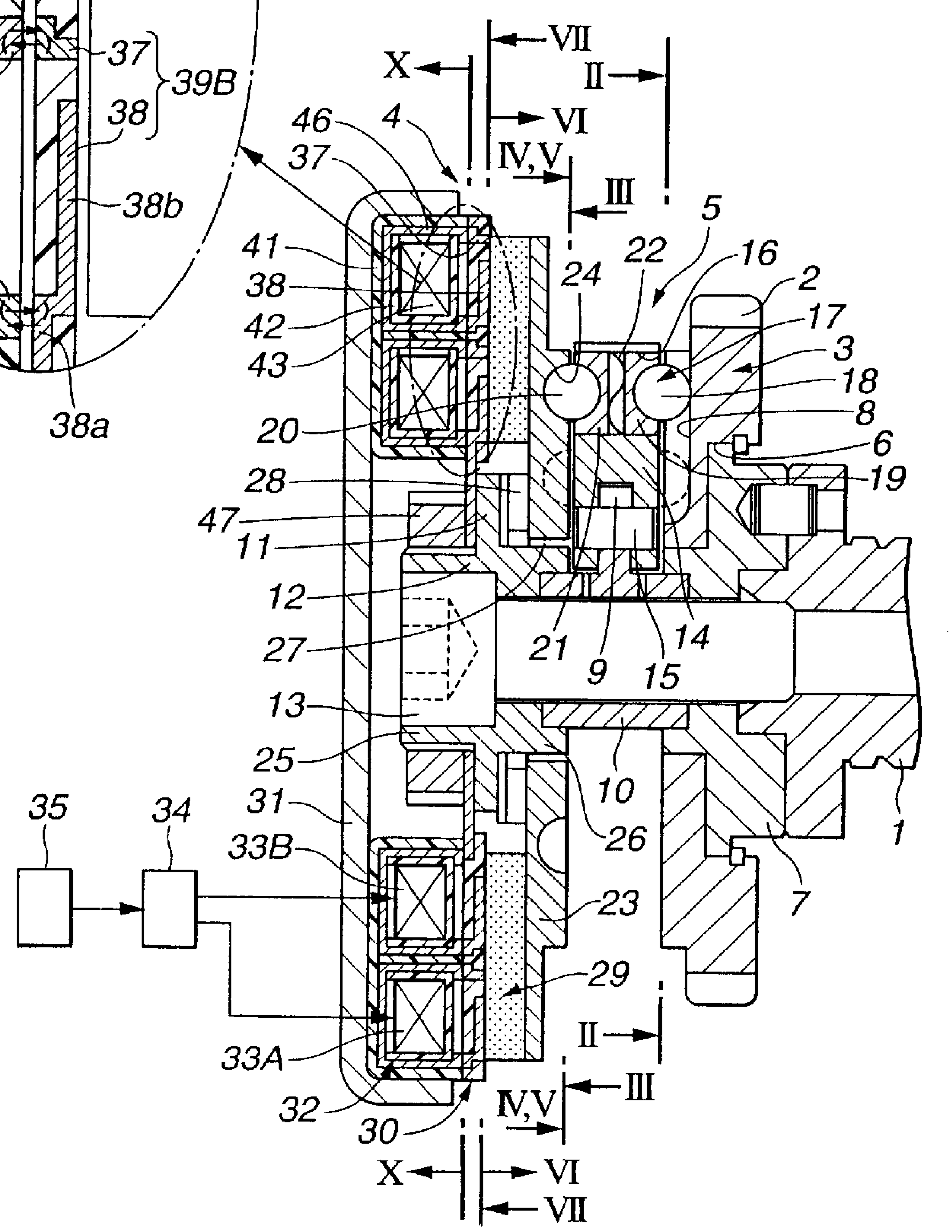

X
VII
II
VI
46
4
IV,V
37
III
5
41
24
22
16
38
2
42
17
43
3
18
20
8
6
28
19
47
11
12
27
21
9
14
15
13
25
10
31
26
35
34
1
33B
7
23
29
II
33A
III
32
IV,V
30
X
VI
VII

FIG. 2

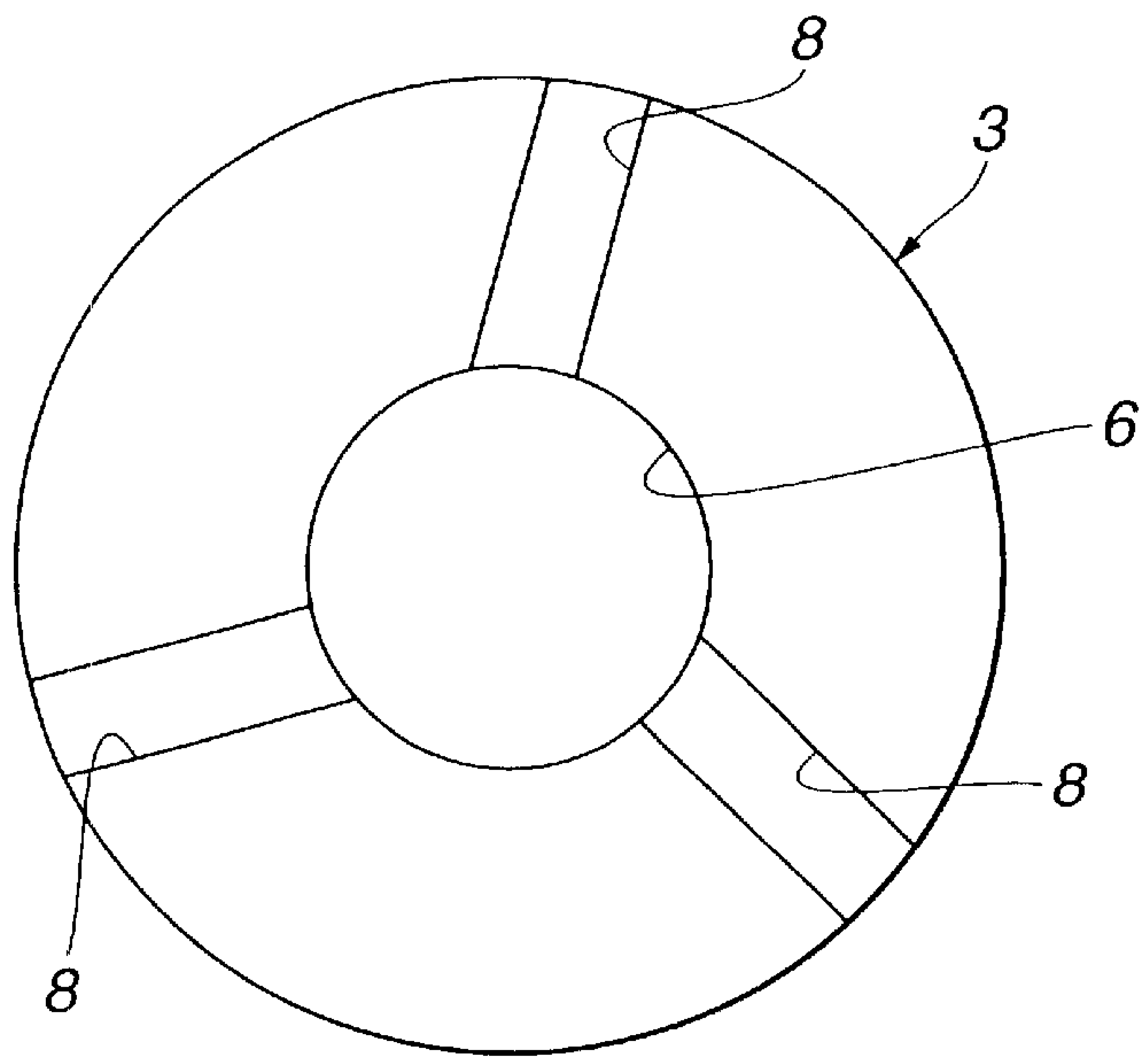


FIG. 3

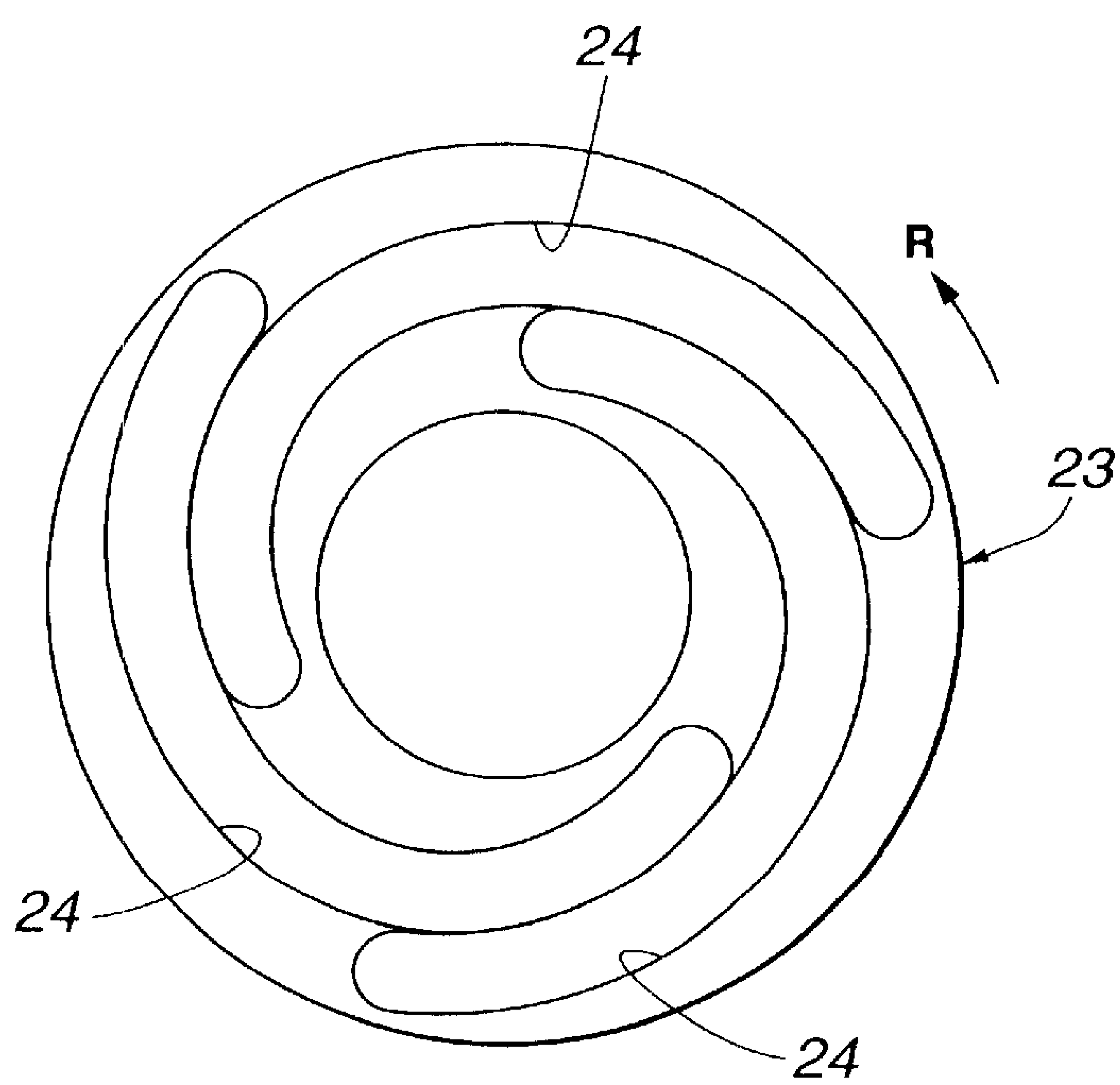
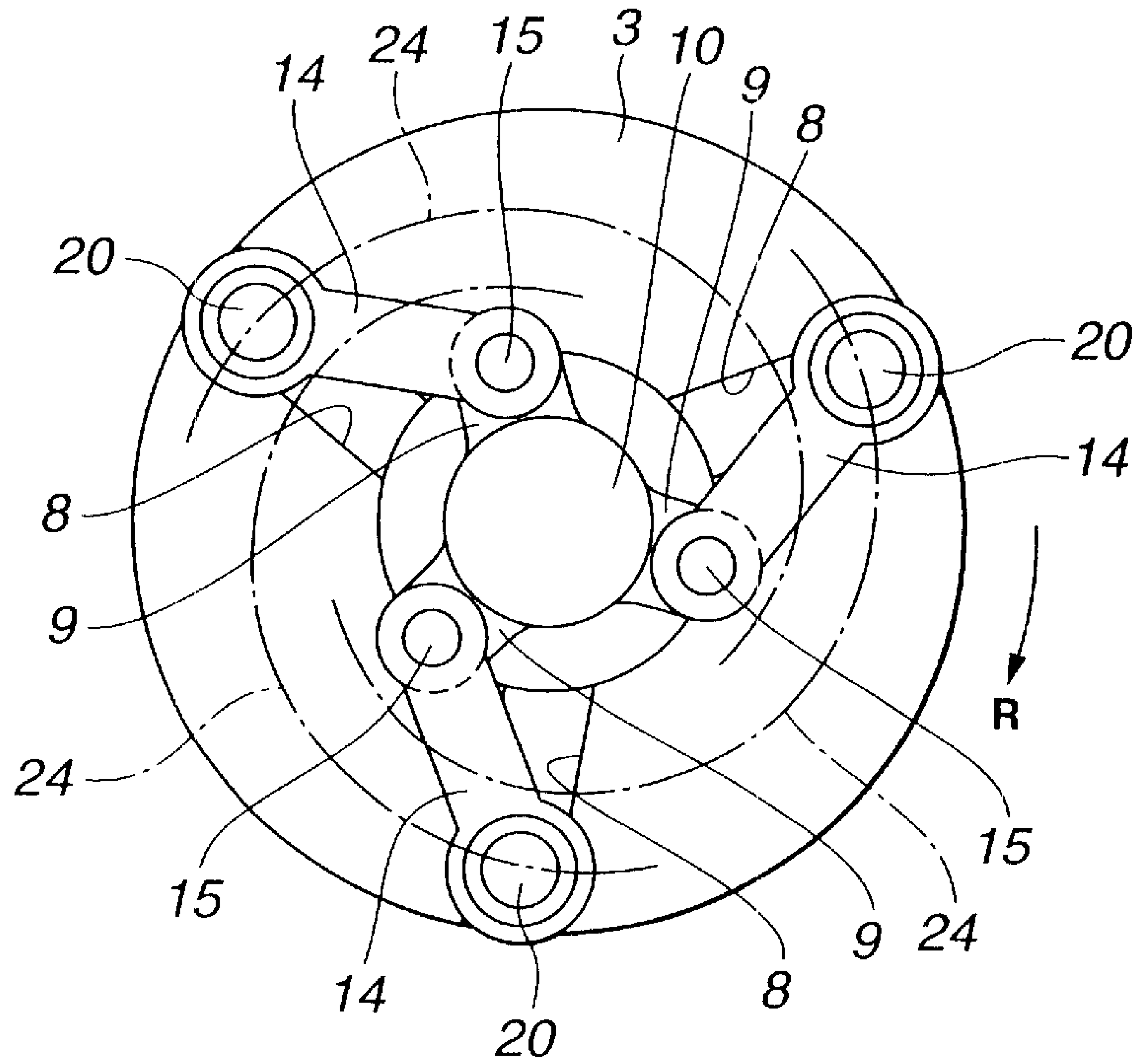


FIG. 4


14
24
15
3
10
9
8
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20
14
8
9
R
24
15
15
9
24
14
8
20

FIG. 5

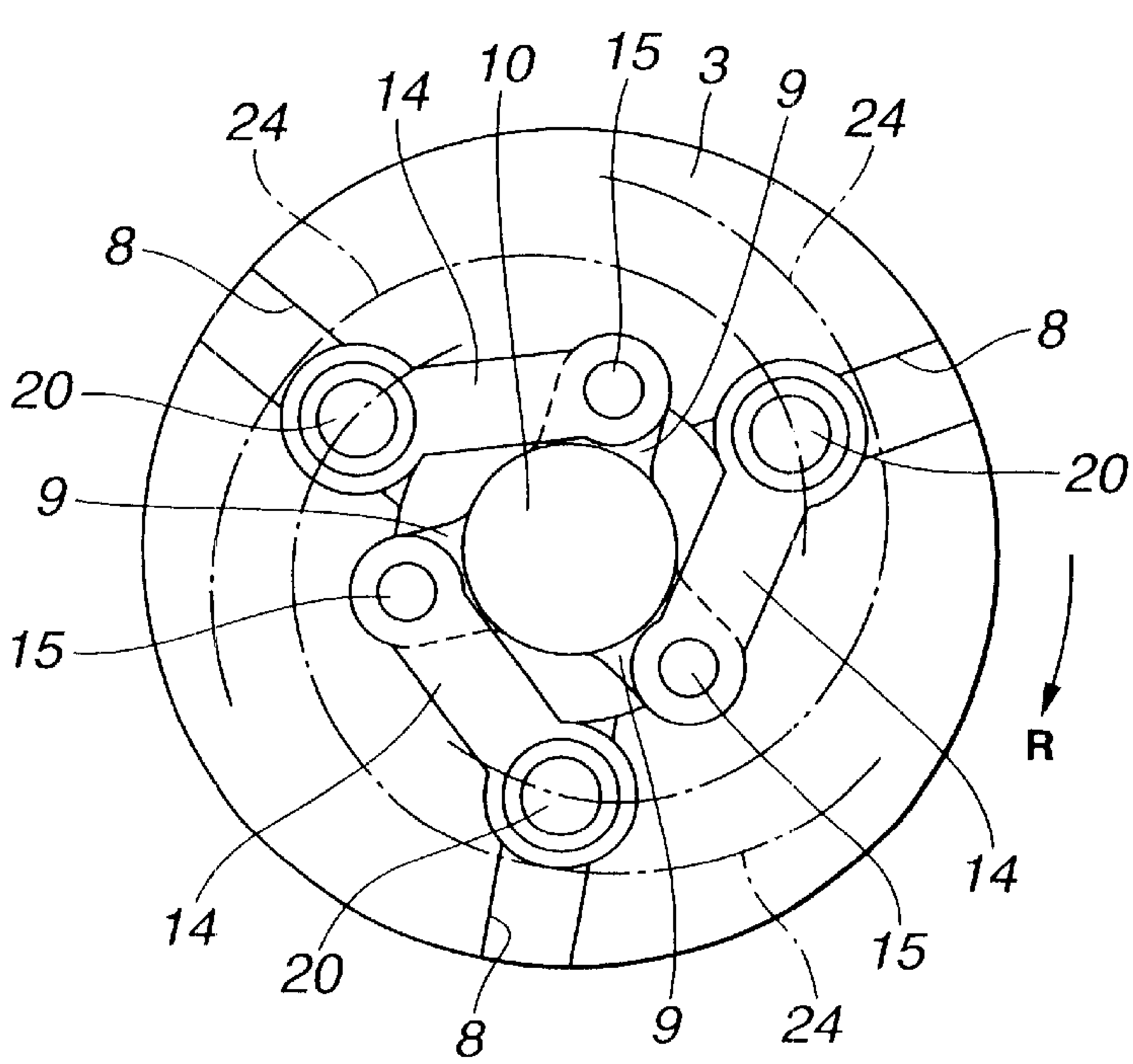

24
14
10
15
3
9
24
8
8
20
20
9
15
R
14
14
20
15
8
9
24

FIG. 6

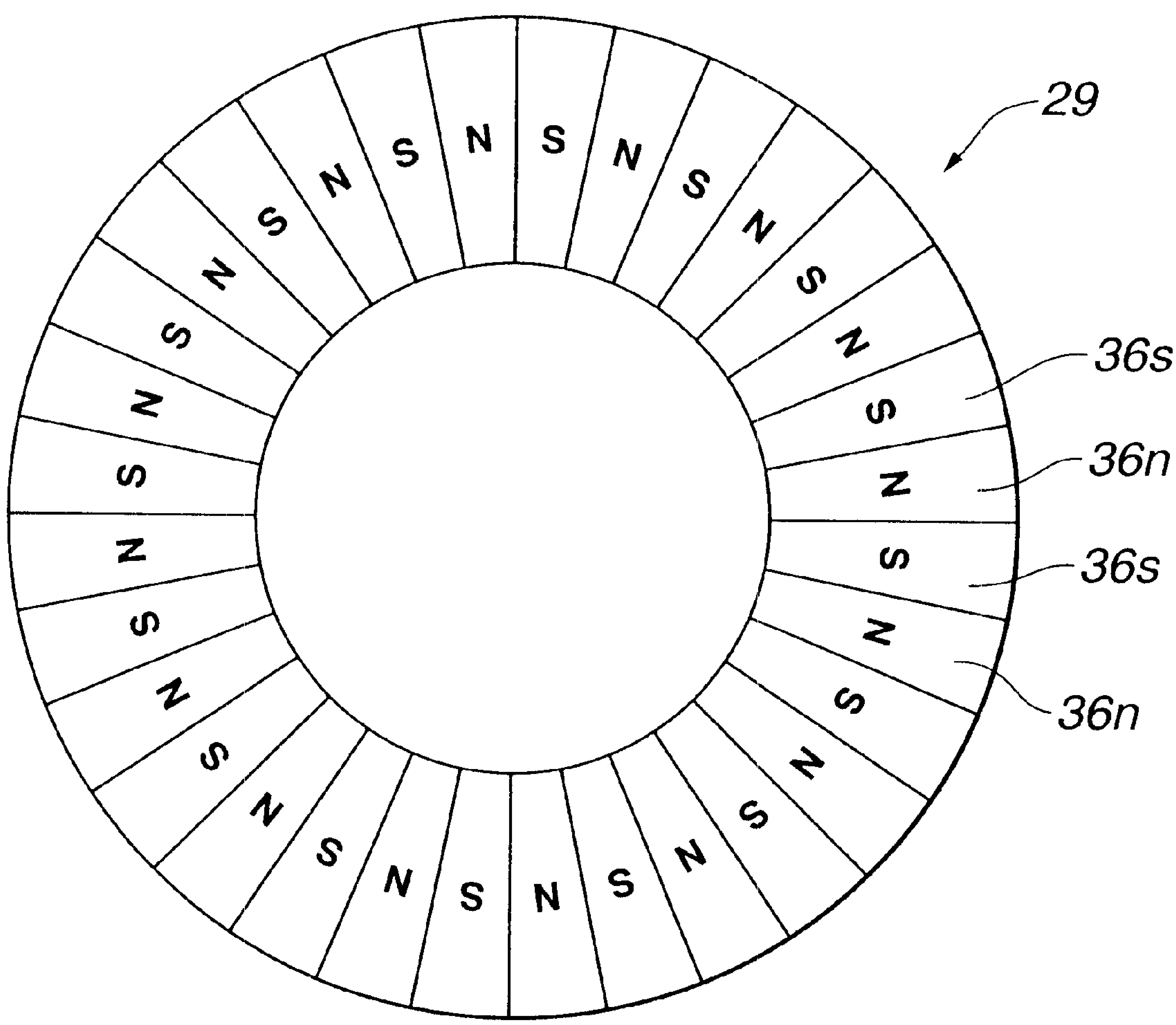


FIG. 7

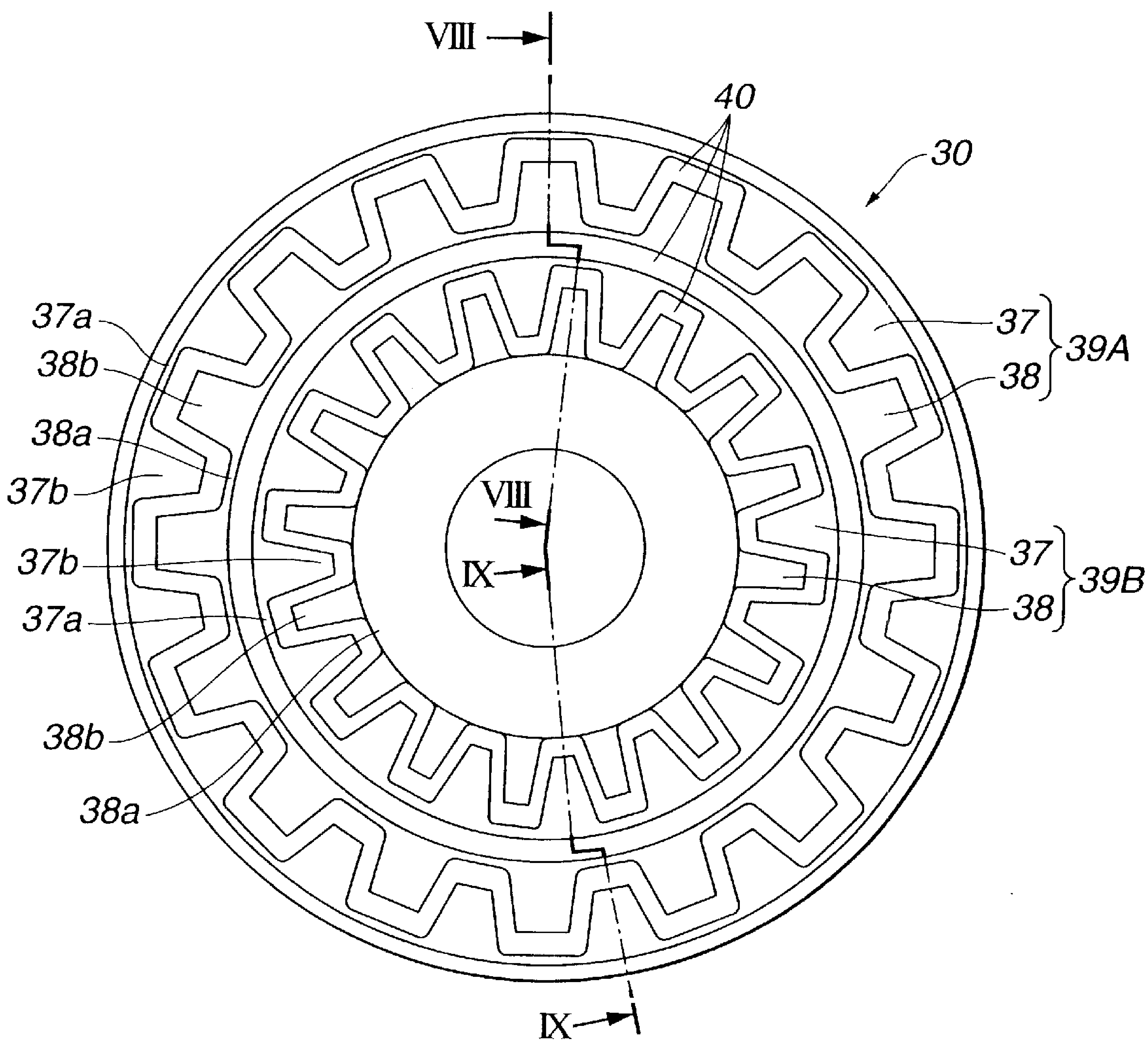

VIII
40
30
37a
38b
38a
37b
37b
37a
38b
38a
37
38
39A
37
38
39B
VIII
IX
IX

FIG. 8

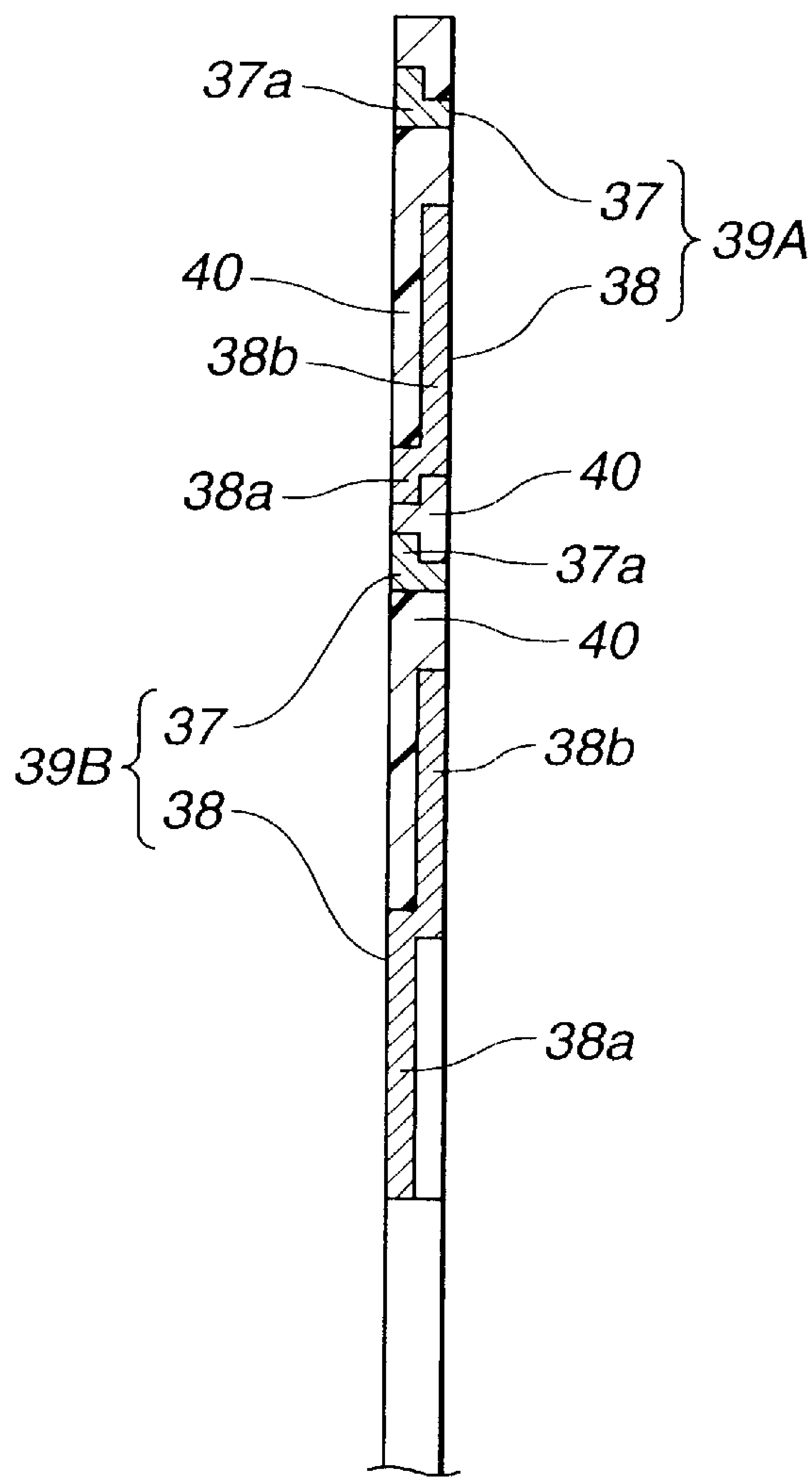

37a
37
38
39A
40
38b
38a
40
37a
40
39B
37
38
38b
38a

FIG. 9

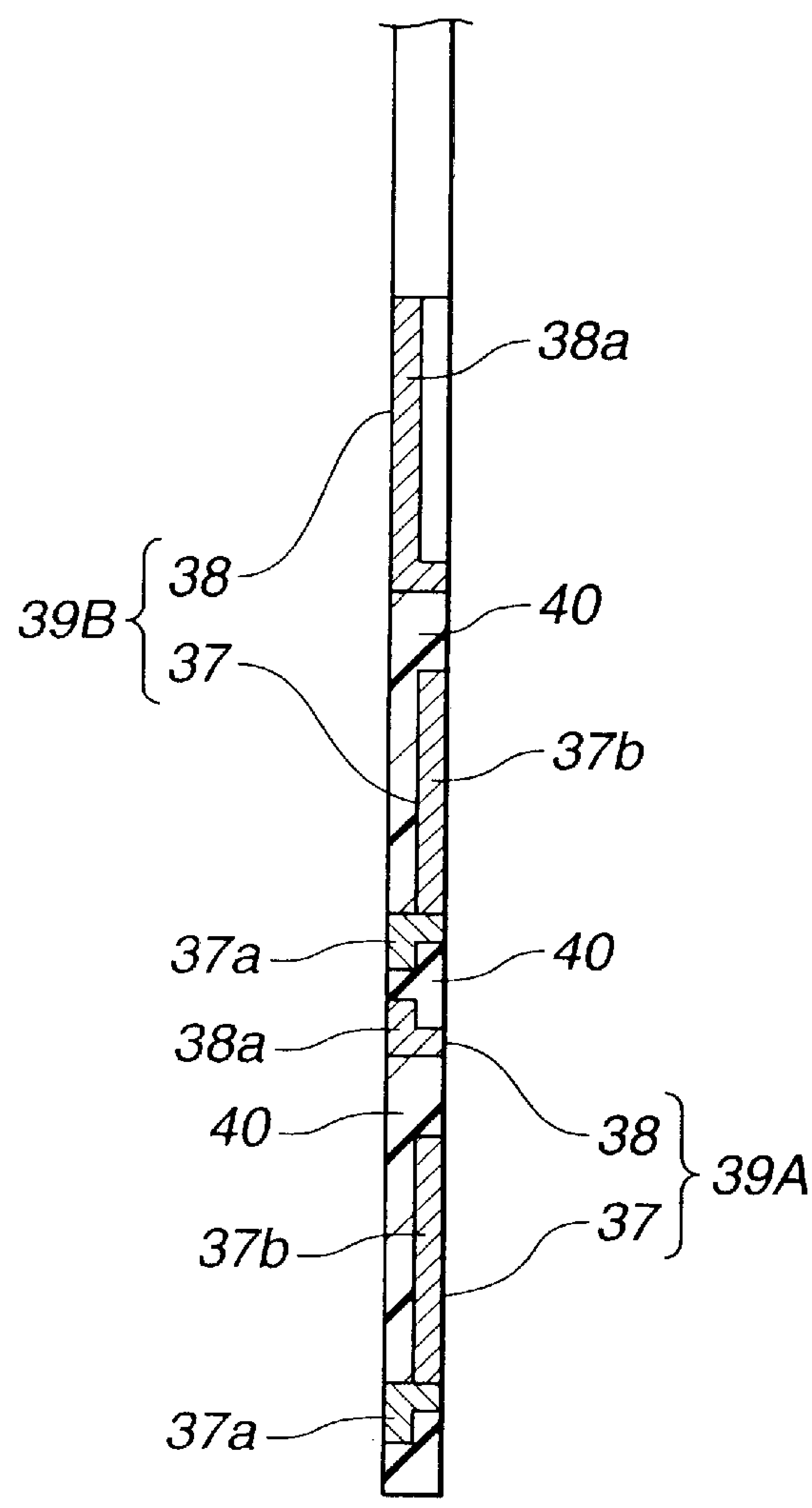

38a
39B
38
37
40
37b
37a
40
38a
40
38
39A
37
37b
37a

FIG. 10

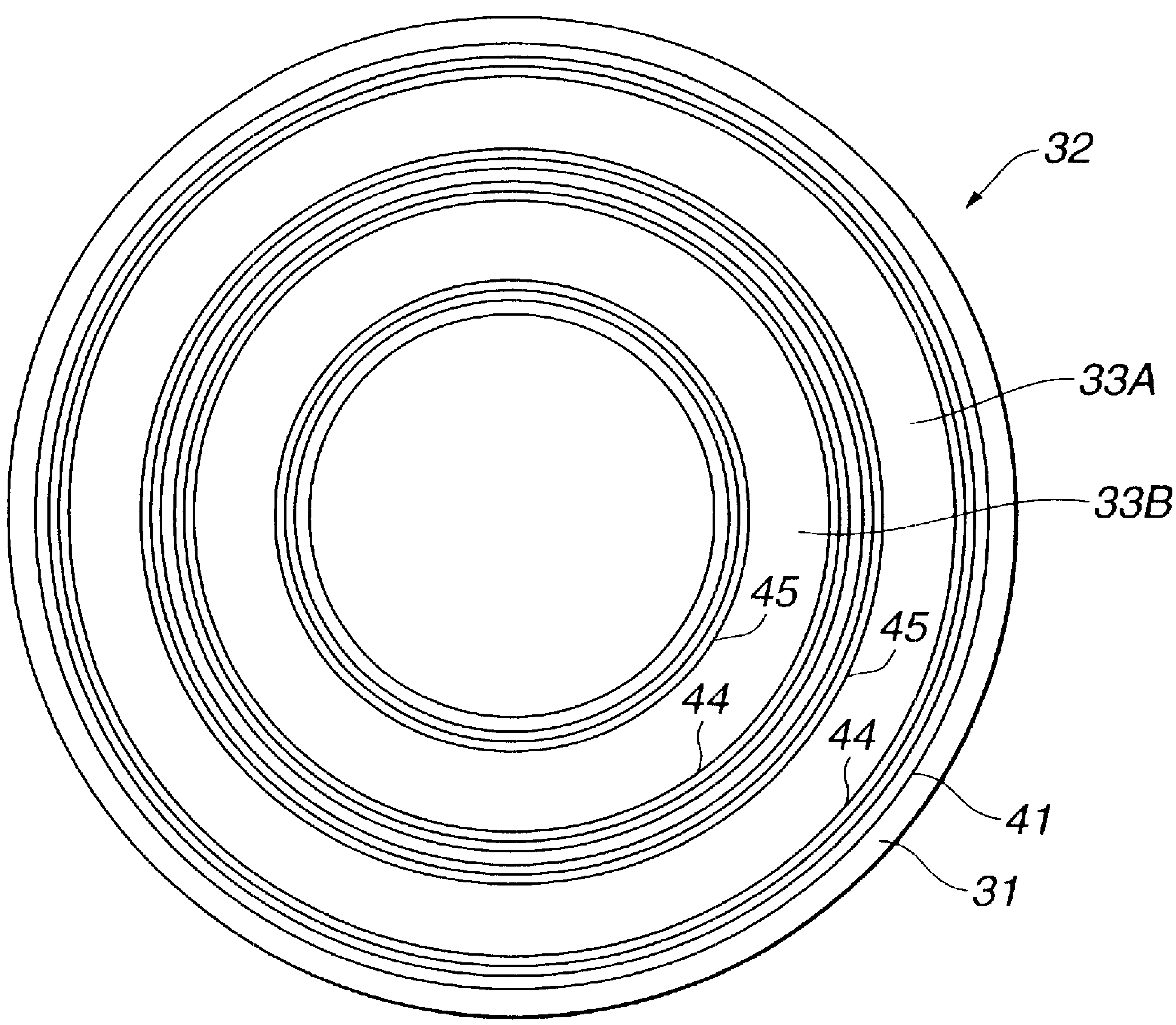


FIG. 11

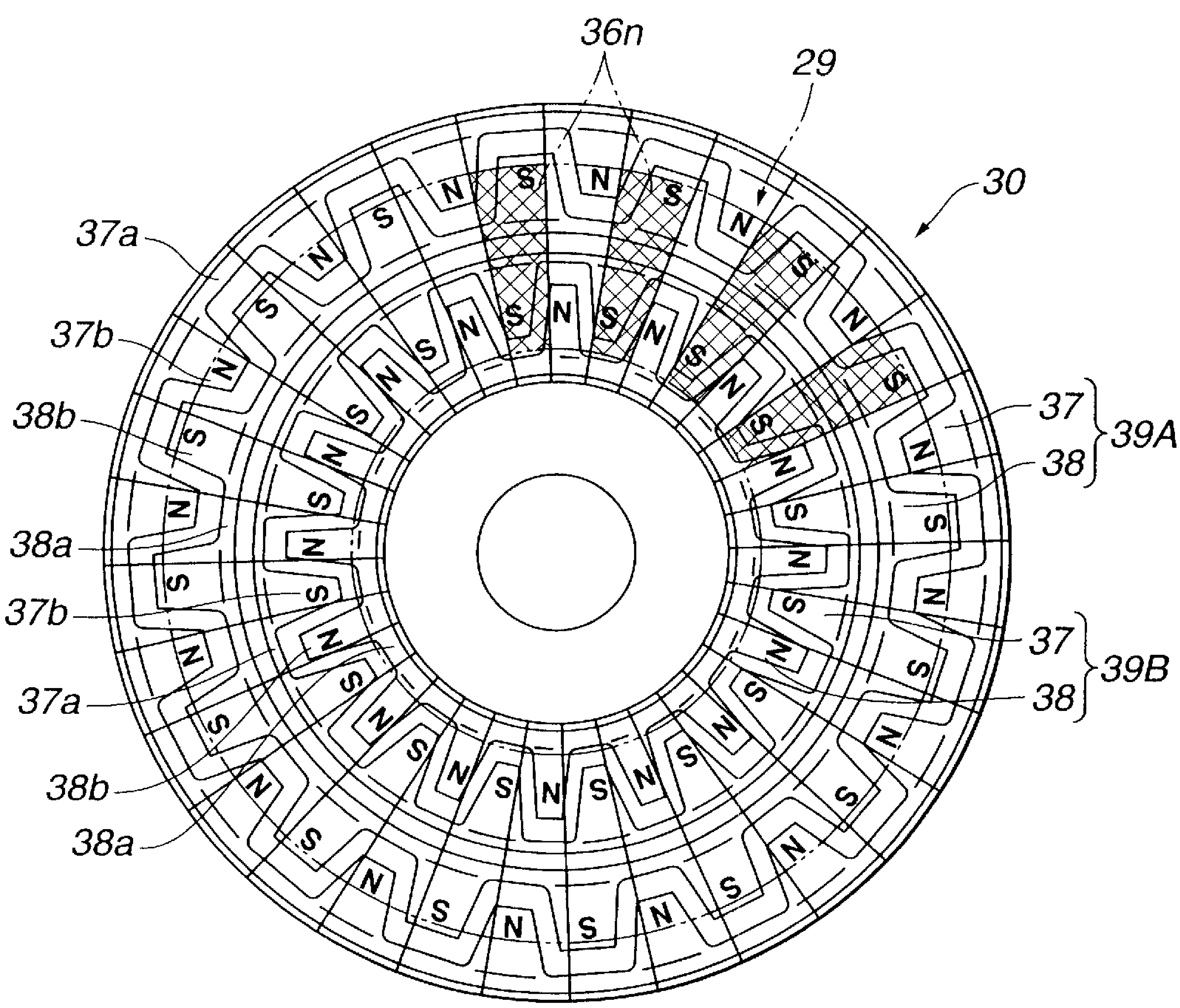


FIG. 12

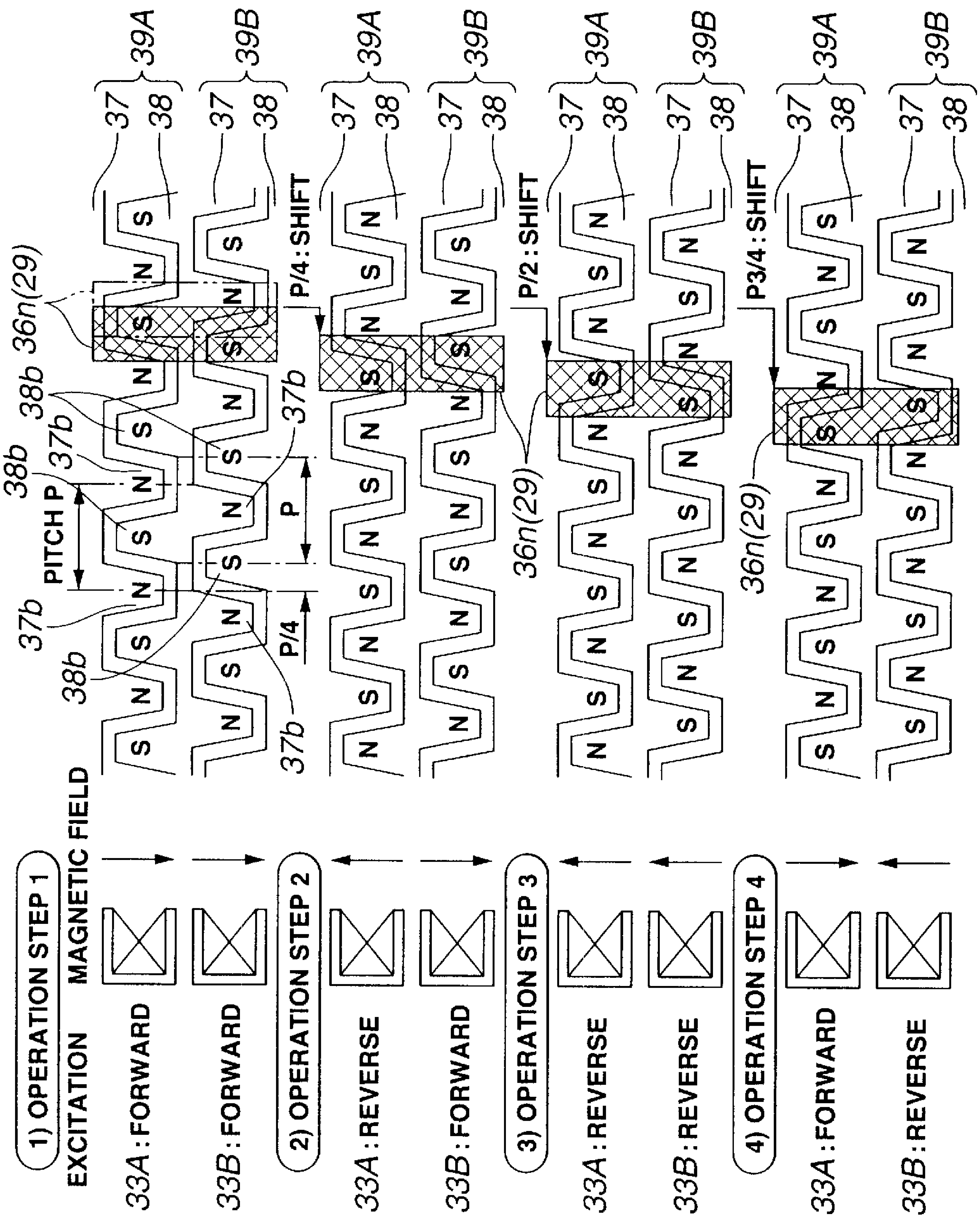

1) OPERATION STEP 1
EXCITATION
MAGNETIC FIELD
33A : FORWARD
33B : FORWARD
2) OPERATION STEP 2
33A : REVERSE
33B : FORWARD
3) OPERATION STEP 3
33A : REVERSE
33B : REVERSE
4) OPERATION STEP 4
33A : FORWARD
33B : REVERSE
PITCH P
P
P/4
P/4 : SHIFT
P/2 : SHIFT
P3/4 : SHIFT
36n(29)
37b
38b
37
38
39A
39B
N
S

FIG. 13B

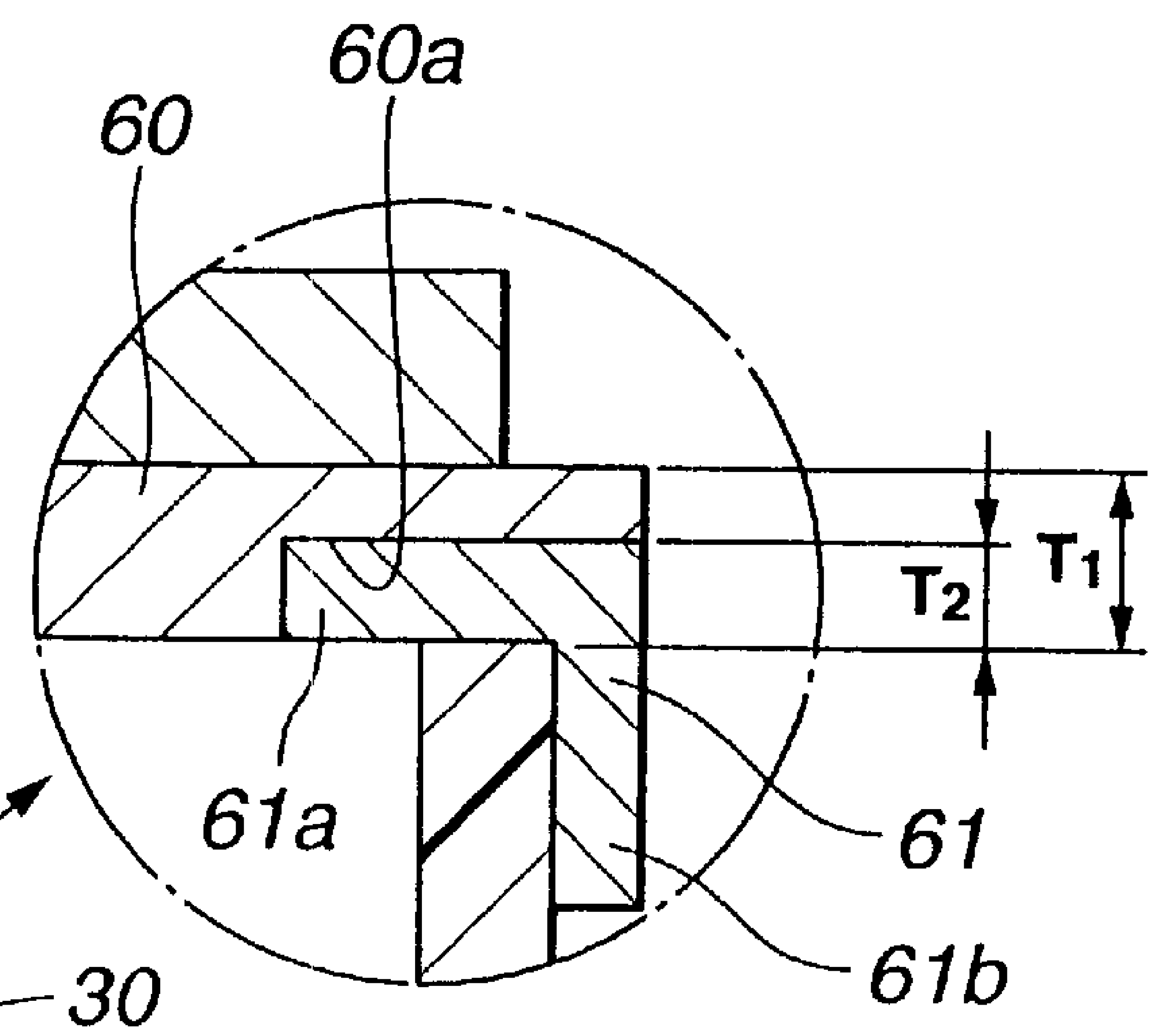


FIG. 13A

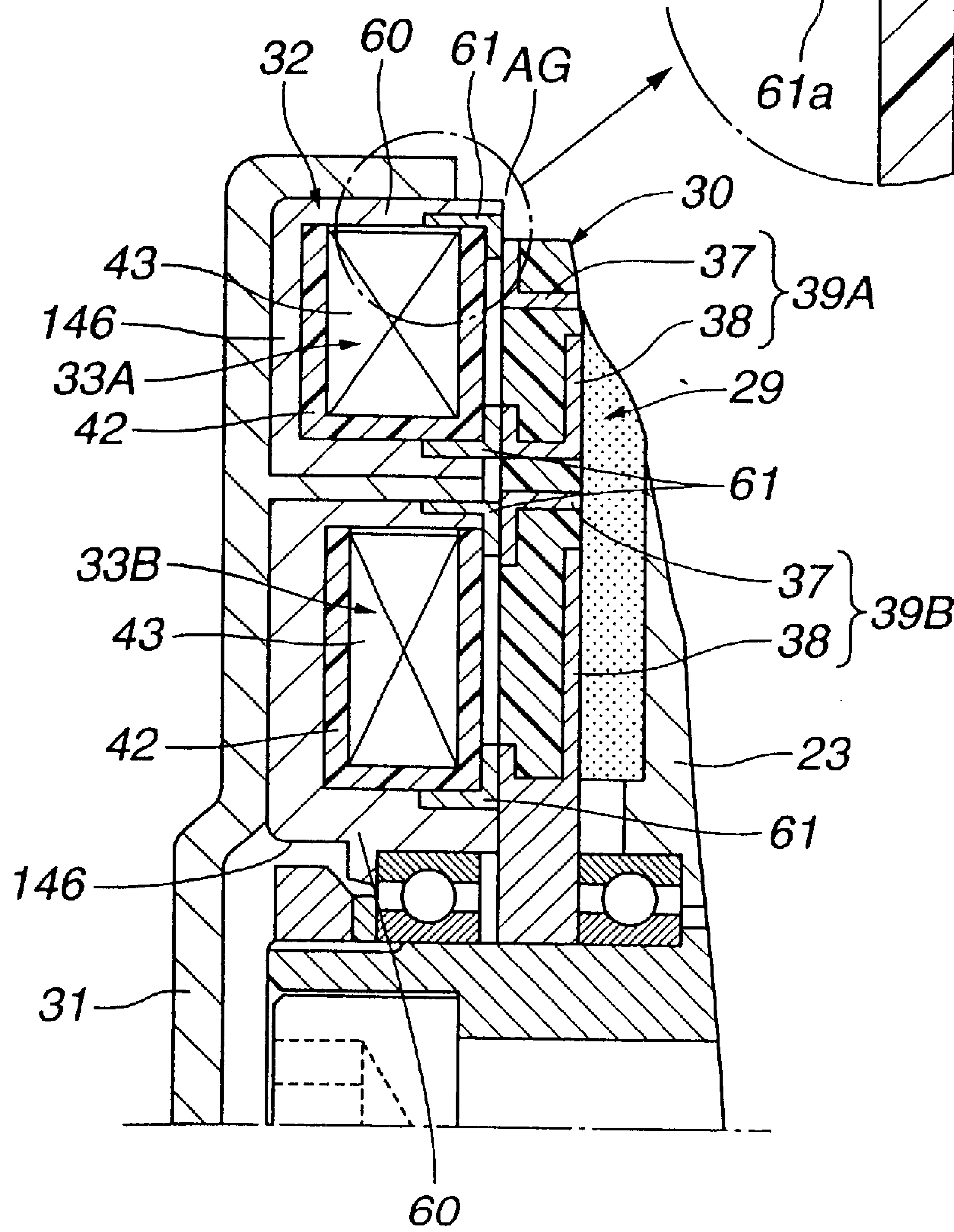
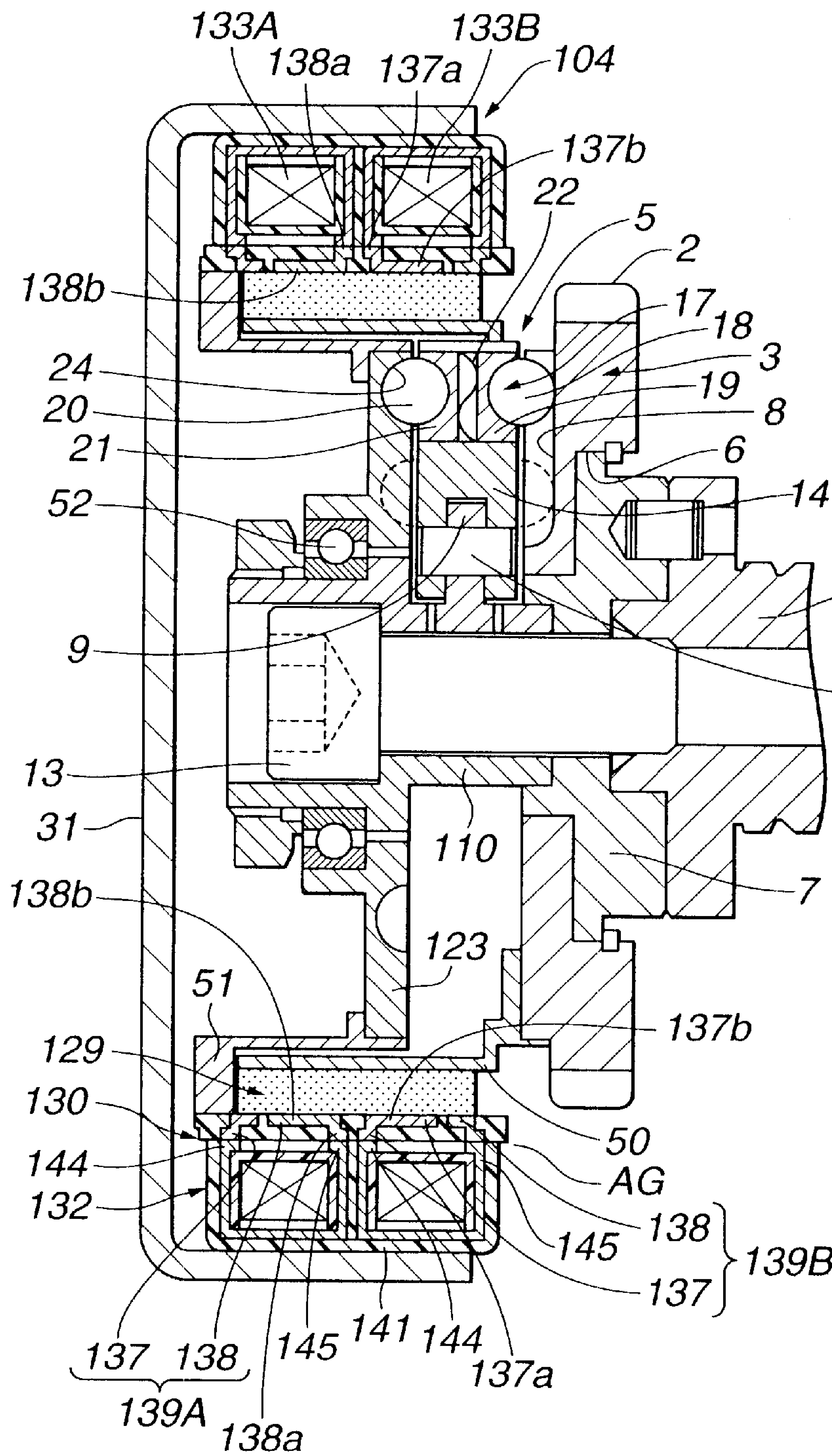
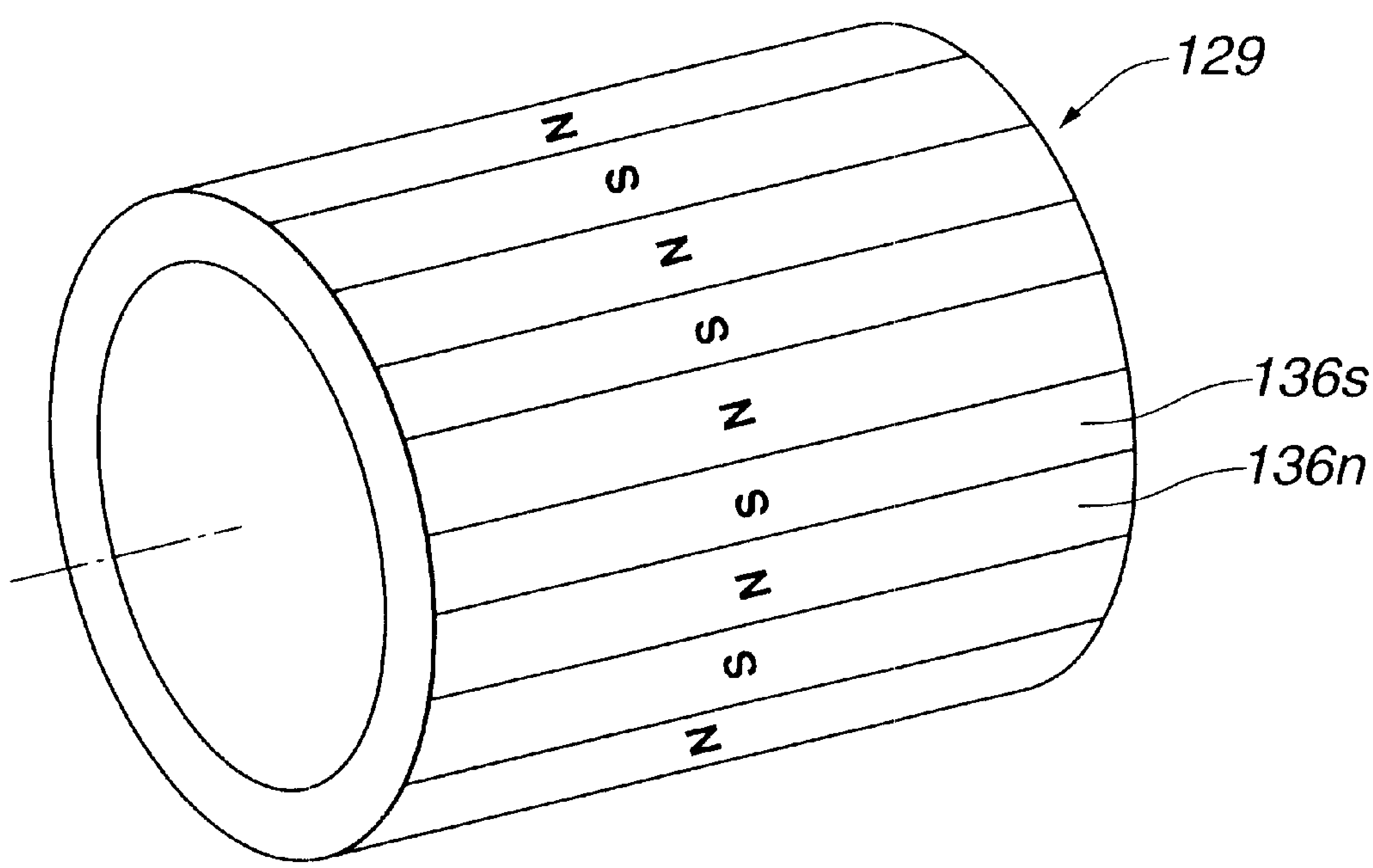


FIG. 14



133A
138a
137a
133B
104
137b
22
5
2
138b
17
18
3
24
19
20
8
21
6
52
14
1
9
15
13
31
110
138b
7
123
51
137b
129
50
130
AG
144
132
138
145
139B
137
137
138
145
141
144
137a
139A
138a

FIG. 15



ROTARY PHASE CONTROLLER, AND VALVE TIMING CONTROLLER OF INTERNAL COMBUSTION ENGINE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a rotary phase controller for varying rotary phase of a drive side and a follower side.

The present invention also relates to a valve timing controller for controlling timing of the internal combustion engine, by varying the rotary phase of the drive side and the follower side.

2. Description of the Related Art

A valve timing controller of an internal combustion engine varies a rotary phase between a drive rotor (which is connected to a crank shaft by way of a timing chain and the like) and a follower rotor (which is connected to a cam shaft side) through revolutionary operation relative to each other, to thereby control open-close timing of the internal combustion engine.

A rotary phase controller such as the valve timing controller described above generally uses fluid pressure. The rotary phase controller using the fluid pressure can assuredly control the rotary phase. The rotary phase controller using the fluid pressure, however, has complicated piping, which is responsible for its likeliness of becoming large in size. In addition, the rotary phase controller using the fluid pressure may have low responsiveness until sufficient fluid pressure is obtained.

Moreover, the following rotary phase controller is devised:

An electric motor gear incorporated between the drive rotor and the follower rotor is rotated so as to revolve the drive rotor relative to the follower rotor when so requested.

The above electric motor gear rotary phase controller can eliminate shortcomings which is caused when using the fluid pressure. The electric motor gear rotary phase gear, however, uses a slip ring and the like which constantly causes an impingement during rotation, and therefore, is low in durability.

Japanese Patent Unexamined Publication No. Heisei 3(1991)-050308 describes a rotary phase controller for varying rotary phase of the drive rotor and the follower rotor by means of a magnetic force (of an electromagnetic coil fixed to an irrotational member) and a spring member.

BRIEF SUMMARY OF THE INVENTION

It is an object of the present invention to provide a rotary phase controller and a valve timing controller (for an internal combustion engine) featuring high durability as well as operation accuracy, by securing a drive rotor and a follower rotor at an arbitrary revolutionary position relative to each other.

According to a first aspect of the present invention, there is provided a rotary phase controller varying rotary phase of a drive rotor and a follower rotor through a relative rotary operation between the drive rotor which is rotatably driven and the follower rotor which receives a power from the drive rotor. The rotary phase controller comprises: a permanent magnet block), a yoke block, and an electromagnetic coil block. The permanent magnet block is disposed on one of the drive rotor's side and the follower rotor's side. The permanent magnet block has a constitution in which different magnetic pole surfaces of a permanent magnet are alternately arranged circumferentially. The yoke block is disposed as a whole on the other of the drive rotor's side and the follower rotor's side. The yoke block includes a plurality of yokes including a first yoke and a second yoke. Each of the plurality of the yokes includes: a first pole tooth ring formed with a plurality of first pole teeth which oppose the magnetic pole surfaces of the permanent magnet block, and a second pole tooth ring formed with a plurality of second pole teeth which oppose the magnetic pole surfaces of the permanent magnet block. The first pole teeth and the second pole teeth are alternately disposed circumferentially. The first yoke and the second yoke are assembled such that the first pole teeth of the first yoke are shifted by a predetermined pitch circumferentially from the second pole teeth of the second yoke. The electromagnetic coil block is fixed to an irrotational member. The electromagnetic coil block includes a plurality of electromagnetic coils including a first electromagnetic coil and a second electromagnetic coil corresponding respectively to the first yoke and the second yoke of the yoke block. Each of the first electromagnetic coil and the second electromagnetic coil has a magnetic input-output end opposing, by way of an air gap, the first pole tooth ring and the second pole tooth ring of the respective first yoke and second yoke. The yoke block and the permanent magnet block make a revolution relative to each other by varying at a predetermined pattern a magnetic field which is generated at the plurality of the electromagnetic coils.

According to a second aspect of the present invention, there is provided a valve timing controller of an internal combustion engine varying rotary phase of a crank shaft and a cam shaft through a relative rotary operation between a drive rotor which is driven by the crank shaft and a follower rotor which is one of the cam shaft and a member coupled to the cam shaft. The valve timing controller comprises: a permanent magnet block), a yoke block, and an electromagnetic coil block. The permanent magnet block is disposed on one of the drive rotor's side and the follower rotor's side. The permanent magnet block has a constitution in which different magnetic pole surfaces of a permanent magnet are alternately arranged circumferentially. The yoke block is disposed as a whole on the other of the drive rotor's side and the follower rotor's side. The yoke block includes a plurality of yokes including a first yoke and a second yoke. Each of the plurality of the yokes includes: a first pole tooth ring formed with a plurality of first pole teeth which oppose the magnetic pole surfaces of the permanent magnet block, and a second pole tooth ring formed with a plurality of second pole teeth which oppose the magnetic pole surfaces of the permanent magnet block. The first pole teeth and the second pole teeth are alternately disposed circumferentially. The first yoke and the second yoke are assembled such that the first pole teeth of the first yoke are shifted by a predetermined pitch circumferentially from the second pole teeth of the second yoke. The electromagnetic coil block is fixed to an irrotational member. The electromagnetic coil block includes a plurality of electromagnetic coils including a first electromagnetic coil and a second electromagnetic coil corresponding respectively to the first yoke and the second yoke of the yoke block. Each of the first electromagnetic coil and the second electromagnetic coil has a magnetic input-output end opposing, by way of an air gap, the first pole tooth ring and the second pole tooth ring of the respective first yoke and second yoke. The yoke block and the permanent magnet block make a revolution relative to each other by varying at a predetermined pattern a magnetic field which is generated at the plurality of the electromagnetic coils.

The other objects and features of the present invention will become understood from the following description with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIGS. **1**A and **1**B (also referred to collectively as FIG. **1**) are views of a longitudinal cross section of a rotary phase controller (valve timing controller), according to a first embodiment of the present invention;

FIG. **2** is a view of an end face taken along the lines II—II in FIG. **1**, according to the first embodiment;

FIG. **3** is a view of an end face taken along the lines III—III in FIG. **1**, according to the first embodiment;

FIG. **4** is a view of an end face taken along the lines IV—IV in FIG. **1**, according to the first embodiment;

FIG. **5** is similar to FIG. **4** but showing an end face taken along the lines V—V in FIG. **1**, for showing operation of the rotary phase controller, according to the first embodiment;

FIG. **6** is a view of an end face taken along the lines VI—VI in FIG. **1**, according to the first embodiment;

FIG. **7** is a view of an end face taken along the lines VII—VII in FIG. **1**, according to the first embodiment;

FIG. **8** is a view of a cross section taken along the lines VIII—VIII in FIG. **7**, according to the first embodiment;

FIG. **9** is a view of a cross section taken along the lines IX—IX in FIG. **7**, according to the first embodiment;

FIG. **10** is a view of an end face of taken along the lines X—X in FIG. **1**, according to the first embodiment;

FIG. **11** shows a schematic side view of a yoke block **30** which is overlapped with imaginary lines of a plurality of north-pole magnetic surfaces **36***n* of a permanent magnet block **29**, according to the first embodiment;

FIG. **12** is a view of an excitation sequence, according to the first embodiment, in which

- shown on the left side are operation step **1** to operation step **4** include:
  - directions of magnetic field and excitation current (of each of a first electromagnetic coil **33**A and a second electromagnetic coil **33**B), and
- shown schematically on the right side include:
  - magnetic poles of each of a first yoke **39**A and a second yoke **39**B corresponding to one of the operation step **1** to operation step **4**, and
  - the north-pole magnetic surface **36***n* of the permanent magnet block **29**;

FIGS. **13**A and **13**B are views of a part of the longitudinal cross section of the rotary phase controller, according to a second embodiment of the present invention;

FIG. **14** is a view of the longitudinal cross section of the rotary phase controller, according to a third embodiment of the present invention; and

FIG. **15** is a perspective view of a permanent magnet block **129**, according to the third embodiment.

DETAILED DESCRIPTION OF THE EMBODIMENTS

In the following, various embodiments of the present invention will be described in detail with reference to the accompanying drawings.

For ease of understanding, the following description will contain various directional terms, such as, left, right, upper, lower and the like. However, such terms are to be understood with respect to only a drawing or drawings on which the corresponding part of element is illustrated.

As is seen in FIG. **1** to FIG. **12**, there is provided a rotary phase controller, according to a first embodiment of the present invention.

As a valve timing controller, the rotary phase controller according to the first embodiment can be applied to a power transmission system on an intake side of an internal combustion engine. Likewise, the rotary phase controller according to the first embodiment can be applied to a power transmission system on an exhaust side of the internal combustion engine.

As is seen in FIGS. **1**A and **1**B (also referred to collectively as FIG. **1**), the valve timing controller is constituted of a cam shaft **1**, a drive plate **3**, a rotary force generator **4**, and a torque amplifier **5**. Cam shaft **1** (otherwise referred to as "follower rotor") is rotatably supported to a cylinder head (not shown) of the internal combustion engine. Drive plate **3** (otherwise referred to as "drive rotor") is mounted to a front end (left in FIG. **1**) of cam shaft **1** in such as manner as to revolve relative to cam shaft **1** when so requested. Drive plate **3** has an outer periphery which is formed with a timing sprocket **2** communicating to a crank shaft (not shown). Rotary force generator **4** is disposed on a front side (left in FIG. **1**) of drive plate **3** and cam shaft **1**. Rotary force generator **4** can generate a rotary force for allowing drive plate **3** and cam shaft **1** to cause a revolution relative to each other. Torque amplifier **5** can amplify the rotary force generated with rotary force generator **4**, so as to directly rotate drive plate **3** and cam shaft **1** with the thus amplified rotary force.

As is seen in FIG. **2**, drive plate **3** is shaped substantially into a disk having a center section formed with a support hole **6** which is stepwise (see FIG. **1**). An inner wall of support hole **6** is rotatably supported with a flange ring **7** which is integrally coupled to the front end of cam shaft **1**. Drive plate **3** has a front face (opposite to a face facing cam shaft **1**) which is formed with three radial slots **8** (otherwise, referred to as "radial guides") extending substantially radially, as is seen in FIG. **2**. Radial slot **8** has a cross section which is substantially semicircular.

As is seen in FIGS. **1**, **4** and **5**, there are provided a lever shaft **10** and a hold ring **12** overlapping with lever shaft **10**. Lever shaft **10** has three levers **9** protruding radially outward. Hold ring **12** has a support flange **11**. Together with flange ring **7**, lever shaft **10** and hold ring **12** are coupled to cam shaft **1** by means of a bolt **13**. As is seen in FIGS. **4** and **5**, there is also provided a link **14** having a first end which is pivotally supported, by way of a pin **15**, to each of three levers **9** of lever shaft **10**. Link **14** has a second end which is formed with a receptacle hole **16** (through hole) extending axially. A movable member **17** is received in receptacle hole **16**.

As is seen in FIG. **1**, movable member **17** is constituted of a first retainer **19**, a second retainer **21**, and a plate spring **22** (wave form). On a first side facing drive plate **3**, first retainer **19** retains a first ball **18**. On the other hand, on a second side opposite to the first side, first retainer **19** retains a second ball **20**. Plate spring **22** is disposed between first retainer **19** and second retainer **21**, so as to bias first retainer **19** and second retainer **21** opposite to each other.

Together with plate spring **22**, first retainer **19** and second retainer **21** are received in receptacle hole **16** of link **14**. Each of first retainer **19** and second retainer **21** is shaped substantially into a thick disk. A front side (right in FIG. **1**) of first retainer **19** has a center section which is formed with a semispherical depression retaining first ball **18**, while a front side (left in FIG. **1**) of second retainer **21** has a center section which is formed with a semispherical depression retaining second ball **20**. Thus, first ball **18** and second ball **20** retained respectively with first retainer **19** and second retainer **21** are coaxially disposed at the second end of link **14**. At the second end of link **14**, first ball **18** and second ball **20** protrude axially opposite to each other.

First ball **18** retained with first retainer **19** engages with radial slot **8** of drive plate **3** in such a manner as to roll. Likewise, second ball **20** retained with second retainer **21** engages with a spiral slot **24** (otherwise, referred to as "spiral guide") in such a manner as to roll, as is seen in FIGS. **1** and **3**. Spiral slot **24** is formed in a middle rotor **23** (to be described afterward), and has a cross section substantially semicircular.

Being guided radially along radial slot **8** of drive plate **3**, movable member **17** is connected to cam shaft **1** by way of link **14** and lever **9**. When an external force is applied to movable member **17** from middle rotor **23**'s side and thereby displacing movable member **17** along radial slot **8**, the above connection of movable member **17** to cam shaft **1** may contribute to the following operation:

A link operation attributable to link **14** and lever **9** will cause revolution between drive plate **3** and cam shaft **1** relative to each other, in a direction and by an angle corresponding to the displacement of movable member **17**.

On the other hand, support flange **11** of hold ring **12** is formed with a first boss section **25** disposed axially forward (leftward in FIG. **1**) and a second boss section **26** disposed axially backward (rightward in FIG. **1**). Around second boss section **26**, there is disposed middle rotor **23** which is shaped substantially into a disk. Middle rotor **23** is formed with a play hole **27** whose inner wall is larger in diameter than second boss section **26**, to thereby causing no contact with second boss section **26**. Moreover, middle rotor **23** has a back face (drive plate **3**'s side) which is formed with three spiral slots **24** each of which corresponds to one of movable members **17**.

As is seen in FIGS. **3** to **5**, each of spiral slots **24** is so formed as to gradually decrease in diameter in a rotational direction R of drive plate **3** (FIGS. **4** and **5** show only a center line of each of spiral slots **24**). The gradual decrease in diameter of spiral slots **24** can contribute to the following operation:

When middle rotor **23** rotates in a lagging direction relative to drive plate **3** with second ball **20** (of movable member **17**) engaging with spiral slot **24**, the movable plate **17** may move radially inward along spiral slot **24**. Contrary to the above, when middle rotor **23** revolves in a leading direction relative to drive plate **3** with second ball **20** (of movable member **17**) engaging with spiral slot **24**, the movable plate **17** may move radially outward along spiral slot **24**.

Between support flange **11** (of hold ring **12**) and an inner periphery (of middle rotor **23**), there is provided a thrust bearing **28** which is shaped substantially into a needle. Middle rotor **23** is rotatably supported to hold ring **12** by way of thrust bearing **28**.

According to the first embodiment, torque amplifier **5** is constituted of radial slot **8** (of drive plate **3**), movable member **17**, link **14**, lever **9**, spiral slot **24** (of middle rotor **23**), and the like. With a rotary force (relative to cam shaft **1**) applied to middle rotor **23** from rotary force generator **4**, torque amplifier **5** can displace movable member **17** radially by way of spiral slot **24**. Moreover, by way of radial slot **8**, link **14** and lever **9**, torque amplifier **5** can amplify the rotary force by a multiplying factor, to thereby apply a relative rotary force to drive plate **3** and cam shaft **1**.

On the other hand, rotary force generator **4** is constituted of a permanent magnet block **29**, a yoke block **30**, and an electromagnetic coil block **32**. Permanent magnet block **29** is shaped substantially into an annular plate which is joined to an outer periphery on a front side (left in FIG. **1**, and opposite to drive plate **3**) of middle rotor **23**. Yoke block **30** is shaped substantially into a thin annular plate which is flanged radially outward from hold ring **12**. Electromagnetic coil block **32** is fixed in a valve timing control cover **31** (an irrotational member) which is so mounted as to stride over the cylinder head (not shown) and a rocker cover (not shown). A first electromagnetic coil **33**A and a second electromagnetic coil **33**B constituting electromagnetic coil block **32** are connected to a drive circuit **34** which includes an excitation circuit, a pulse distributor circuit, and the like. A controller **35** can control drive circuit **34**. Controller **35** can receive various input signals such as crank angle, cam angle, engine speed, engine load and the like, to thereby output control signals to drive circuit **34** in accordance with operating states of the internal combustion engine.

As is seen in FIG. **6**, permanent magnet block **29** defines a surface (orthogonal to the axis) which is formed with a plurality of magnetic poles (N-pole and S-pole) extending radially. The N-poles and the S-poles are alternately arranged circumferentially. In FIG. **6**, a north-pole magnetic surface **36*n*** signifies the N-pole, while a south-pole magnetic surface **36*s*** signifies the S-pole.

As is seen in an enlarged part of FIG. **1**, yoke block **30** is constituted of a pair of a first yoke **39**A and a second yoke **39**B (to be described afterward). Each of first yoke **39**A and second yoke **39**B has a pair of a first pole tooth ring **37** and a second tooth ring **38**. Yoke block **30** has an inner periphery which is securely disposed between a support flange **11** (of hold ring **12**) and a nut **47**, where the nut **47** is screwed down on first boss section **25** on the front side of hold ring **12**.

First pole tooth ring **37** and second pole tooth ring **38** of each of first yoke **39**A and second yoke **39**B are made of metal material having high permeability. As is seen in FIG. **7**, First pole tooth ring **37** and second pole tooth ring **38** have, respectively, a first base section **37*a*** and a second base section **38*a***, each of which is shaped substantially into a flat ring. Moreover, first pole tooth ring **37** and second pole tooth ring **38** have, respectively, a plurality of first pole teeth **37*b*** and a plurality of second pole teeth **38*b***, each of which is shaped substantially into a trapezium. First pole teeth **37*b*** extend radially inward, while second pole teeth **38*b*** extend radially outward.

According to the first embodiment, first pole tooth ring **37** is disposed radially outward, while second pole tooth ring **38** is disposed radially inward. First pole teeth **37*b*** (of first pole tooth ring **37**) and second pole teeth **38*b*** (of second pole tooth ring **38**) are disposed at regular angular intervals circumferentially. In addition, First pole teeth **37*b*** have addenda directing toward second base section **38*a***, while second pole teeth **38*b*** have addenda directing toward first base section **37*a***. In other words, the addenda of first pole teeth **37*b*** extend radially inward, while the addenda of second pole teeth **38*b*** extend radially outward. First pole teeth **37*b*** (of first pole tooth ring **37**) and second pole teeth **38*b*** (of second pole tooth ring **38**) are disposed alternately circumferentially in such a manner as to define equidistant pitches. First pole tooth ring **37** and second pole tooth ring **38** are coupled to each other by way of a resin material **40** (insulator).

First yoke **39**A and second yoke **39**B constitute yoke block **30**. First yoke **39**A is disposed radially outside, while second yoke **39**B is disposed radially inside. First yoke **39**A and second yoke **39**B are so arranged as to form an entire configuration shaped substantially into a disk.

As is seen in FIG. **12** (excitation sequence), first yoke **39**A and second yoke **39**B are mounted such that first pole teeth **37***b* and second pole teeth **38***b* are shifted by ¼ pitches circumferentially.

Hereinabove, one pitch is defined as a distance between adjacent two of first pole teeth **37***b* (or second pole teeth **38***b*) on first pole tooth ring **37** (or second pole tooth ring **38**).

Otherwise, the one pitch may be defined in the following manner:

The one pitch is a distance between first pole tooth **37***b* (on first pole tooth ring **37**) and second pole tooth **38***b* (on second pole tooth ring **38**) adjacent to each other. In this case, first pole teeth **37***b* and second pole teeth **38***b* can be interpreted as being shifted by ½ pitches circumferentially.

As is seen in FIG. **1**, yoke block **30** has a first side (left in FIG. **1**) axially facing electromagnetic coil block **32** and a second face (right in FIG. **1**) axially facing permanent magnet block **29**.

As is seen in FIGS. **8** and **9**, first base section **37***a* (of first pole tooth ring **37**) and second base section **38***a* (of second pole tooth ring **38**) of each of first yoke **39**A and second yoke **39**B are disposed on a side (left in FIGS. **8** and **9**) facing electromagnetic coil block **32**. Moreover, as is seen in FIGS. **8** and **9**, first pole tooth **37***b* and second pole tooth **38***b* of each of first yoke **39**A and second yoke **39**B are disposed on a side (right in FIGS. **8** and **9**) facing permanent magnet block **29**.

For allowing disposition described above, a connection is bent between first pole tooth **37***b* and first base section **37***a* (FIG. **9**), while a connection is bent between second pole tooth **38***b* and second base section **38***a* (FIG. **8**). Like first pole tooth ring **37** and second pole tooth ring **38**, first yoke **39**A (of yoke block **30**) and second yoke **39**B (of yoke block **30**) are coupled to each other by way of resin material **40** (insulator).

Thus, all first pole tooth rings **37** and second pole tooth rings **38** adjacent to each other can be firmly joined to resin material **40** by a large area including side faces of first base section **37***a* and second base section **38***a*, and side faces of first pole teeth **37***b* and second pole teeth **38***b*. In addition, first base section **37***a* (of first pole tooth ring **37**) and second base section **38***a* (of second pole tooth ring **38**) can be so disposed as to be close enough to electromagnetic coil block **32**, while first pole teeth **37***b* and second pole teeth **38***b* can be so disposed as to be close enough to permanent magnet block **29**. Resin material **40** (insulator) is filled between all of first pole tooth rings **37** and second pole tooth rings **38** of yoke block **30**, to thereby prevent any unnecessary magnetic flux leak from between first pole tooth ring **37** and second pole tooth ring **38** adjacent to each other. Moreover, resin material **40** can prevent any eddy current which may be caused by rotation of yoke block **30**.

Yoke block **30** can be molded for example in the following operations (preferable):

1. Dispose first pole tooth ring **37** and second pole tooth ring **38** of each of first yoke **39**A and second yoke **39**B in a mold in a predetermined manner.
2. Flow resin material **40** into the mold, so as to fill an area between first pole tooth ring **37** and second pole tooth ring **38** with resin material **40**.

Molding yoke block **30** in the above operations is accurate and can facilitate assembly of all first pole tooth rings **37** and second pole tooth rings **38**, improving production efficiency as well as molding accuracy.

On the other hand, as is seen in FIGS. **1** and **10**, electromagnetic coil block **32** has two-phase electromagnetic coil, that is, first electromagnetic coil **33**A and second electromagnetic coil **33**B which are radially arranged, respectively, outward and inward. Electromagnetic coil block **32** is received in a housing **41** which is fixed in valve timing control cover **31** and has an opening on a side of yoke block **30**.

Each of first electromagnetic coil **33**A and second electromagnetic coil **33**B is constituted of a coil body **43** and a coil yoke **46**. Coil body **43** winds around an annular bobbin **42**. Coil yoke **46** is disposed around coil body **43**, and induces magnetic flux (caused to coil body **43**) to a first magnetic input-output end **44** and a second magnetic input-output end **45** which are disposed on a side facing yoke block **30**. As is seen in the enlarged part of FIG. **1**, first magnetic input-output end **44** of each of first electromagnetic coil **33**A and second electromagnetic coil **33**B faces, via an axial air gap AG, first base section **37***a* of first pole tooth ring **37** of yoke block **30**, while second magnetic input-output end **45** of each of first electromagnetic coil **33**A and second electromagnetic coil **33**B faces, via air gap AG, second base section **38***a* of second pole tooth ring **38** of yoke block **30**.

Magnetizing first electromagnetic coil **33**A and second electromagnetic coil **33**B will generate a magnetic field in a predetermined direction, to thereby cause a magnetic induction (corresponding to the thus generated magnetic field) to first yoke **39**A (facing first electromagnetic coil **33**A via air gap AG) and second yoke **39**B (facing second electromagnetic coil **33**B via air gap AG). Hereinabove, whether or not the magnetic induction is caused is not influenced by the rotation of yoke block **30**. As a result, first pole tooth ring **37** and second pole tooth ring **38** of each of first yoke **39**A and of second yoke **39**B will have magnetic pole corresponding to the direction of the magnetic field.

The magnetic field generated by first electromagnetic coil **33**A and second electromagnetic coil **33**B can be switched sequentially in accordance with a predetermined pattern corresponding to pulse inputted from drive circuit **34**. More specifically, the switching pattern of the magnetic field of first electromagnetic coil **33**A and second electromagnetic coil **33**B can be shown, for example, by the excitation sequence, as is seen in FIG. **12**.

In FIG. **12**, a downward arrow ↓ indicates the magnetic field which is generated by first electromagnetic coil **33**A and second electromagnetic coil **33**B with first pole tooth ring **37** (of yoke block **30**) featuring N-pole and second pole tooth ring **38** (of yoke block **30**) featuring S-pole. Contrary to the above, an upward arrow ↑ indicates the magnetic field which is generated by first electromagnetic coil **33**A and second electromagnetic coil **33**B with first pole tooth ring **37** featuring S-pole and second pole tooth ring **38** featuring N-pole.

Moreover, first electromagnetic coil **33**A and second electromagnetic coil **33**B in FIG. **12** are wound in a form of a monofiler. "FORWARD" of "EXCITATION" indicates excitation current direction corresponding to downward arrow ↓, while "REVERSE" of "EXCITATION" indicates excitation current direction corresponding to upward arrow ↑.

Hereinafter described step by step are the switching patterns in FIG. **12**:

At step **1**, allowing first electromagnetic coil **33**A to feature the excitation current "FORWARD" will generate the magnetic field indicated by downward arrow ↓, and second electromagnetic coil **33**B to feature the excitation current "FORWARD" will generate the magnetic field indicated by downward arrow ↓. Thus, first pole tooth ring **37** of each of first yoke **39**A and second yoke **39**B may feature N-pole, while second pole tooth ring **38** of each of first yoke **39**A and second yoke **39**B may feature S-pole. With repulsion against first pole teeth **37***b* (N-pole) and attraction toward second pole teeth **38***b* (S-pole), north-pole magnetic surface **36***n* (N-pole) of permanent magnet block **29** (which was originally placed in a position indicated by two-dot chain line in FIG. **12**) may be shifted by ¼ pitches in one direction (leftward in FIG. **12**), so as to face second pole tooth **38***b* (S-pole) of first yoke **39**A and second pole tooth **38***b* (S-pole) of second yoke **39**B in a striding manner.

Likewise at step **2**, the excitation currents of first electromagnetic coil **33**A and second electromagnetic coil **33**B are respectively "REVERSE" and "FORWARD," to thereby generate the magnetic fields indicated respectively by upward arrow ↑ and downward arrow ↓.

Likewise at step **3**, the excitation currents of first electromagnetic coil **33**A and second electromagnetic coil **33**B are respectively "REVERSE" and "REVERSE," to thereby generate the magnetic fields indicated respectively by upward arrow ↑ and upward arrow ↑.

Likewise at step **4**, the excitation currents of first electromagnetic coil **33**A and second electromagnetic coil **33**B are respectively "FORWARD" and "REVERSE," to thereby generate the magnetic fields indicated respectively by downward arrow ↓ and upward arrow ↑.

From step **1** to step **4**, first pole teeth **37***b* and/or second pole teeth **38***b* featuring S-pole may be shifted by ¼ pitches in the one direction (leftward in FIG. **12**). Thus, permanent magnet block **29** may rotate in such a manner that north-pole magnetic surface **36***n* follows the shift of the S-pole of first pole teeth **37***b* and/or second pole teeth **38***b*.

Thereby, repetition of the switching patterns of the generated magnetic field can continue revolution (in the one direction) of permanent magnet block **29** relative to yoke block **30**. Backward repetition of the switching pattern of the generated field can continue revolution (in opposite direction) of permanent magnet block **29** relative to yoke block **30**. Moreover, stopping the switching patterns of the generated magnetic field in electromagnetic coil block **32** may stop the revolution of permanent magnet block **29** relative to yoke block **30**. The thus stop position can be securely maintained by dint of the magnetic attraction-repulsion which continues to act between first and second pole teeth **37***b*, **38***b* (of yoke block **30**) and north and south-pole magnetic surfaces **36***n*, **36***s* (of permanent magnet block **29**).

With rotary force generator **4** having the constitution described above, permanent magnet block **29** can freely revolve relative to yoke block **30** by dint of a force generated at electromagnetic coil block **32** (irrotational). Moreover, rotary force generator **4** can securely maintain the relative revolution position.

In addition, energizing rotary force generator **4** does not require slip ring and the like. Therefore, rotary force generator **4** has a good durability for long time operation.

Moreover, electromagnetic coil block **32** generating the magnetic field does not rotate integrally with the power transmission system of the rotary phase controller (valve timing controller), thereby reducing inertia force of the rotary section of the rotary phase controller. With this, the rotary phase controller (valve timing controller) can be reduced in load applied thereto, and improved in operational responsiveness.

The method of winding first electromagnetic coil **33**A and second electromagnetic coil **33**B is not limited to the monofiler. Other method is allowed such as bifiler. The bifiler method can simplify the excitation circuit in drive circuit **34** as compared with the monofiler method, to thereby further reduce the production cost.

In the valve timing controller described above, permanent magnet block **29** (middle rotor **23**) can freely revolve relative to yoke block **30** according to an instruction from controller **35**, whether or not yoke block **30** (cam shaft **1**) is rotating or not. In addition, the valve timing controller can continue securing position of the relative revolution, to thereby freely vary rotary phase of the crank shaft (not shown) relative to cam shaft **1**.

Namely, securing in advance an angle of mounting drive plate **3** and lever shaft **10** on a most lagging angle side as is seen in FIG. **5** during idling or starting of the internal combustion engine can maintain the rotary phase (opening-closing timing of the internal combustion engine) of the crank shaft (not shown) relative to cam shaft **1** on the most lagging angle side, to thereby stabilize rotation of the internal combustion engine and reduce fuel consumption.

Then, for example, as the internal combustion engine shifts from the above state to the normal operating state in which the instruction is carried out from controller **35** to drive circuit **34** (of first electromagnetic coil **33**A and second electromagnetic coil **33**B) for varying the rotary phase to the most leading angle side, electromagnetic coil block **32** can switch the generated magnetic field at the predetermined pattern in accordance with the instruction. Thereby, electromagnetic coil block **32** can rotate permanent magnet block **29** and middle rotor **23** to the most leading angle. Thereby, movable member **17** (second ball **20**) is guided along spiral slot **24** of middle rotor **23**, and thereby is shifted most outside radially, as is seen in FIG. **4**. With this, the angle of mounting drive plate **3** and lever shaft **10** can be shifted to the most leading angle side by way of link **14** and lever **9**. As a result, rotary phase between the crank shaft (not shown) and cam shaft **1** can be shifted to the most leading angle, to thereby increase the output of the internal combustion engine.

In the case of the valve timing controller described above, continuation of the excitation of each of first electromagnetic coil **33**A and second electromagnetic coil **33**B is allowed after the rotary phase shift as described above. Excitation of the electromagnetic coil **33**A and second electromagnetic coil **33**B is, however, stopped after the rotary phase shift. Even after the excitation stop of first electromagnetic coil **33**A and second electromagnetic coil **33**B, the magnetic force of permanent magnet block **29** can attract first pole tooth ring **37** and second pole tooth ring **38**. Thus, the rotary phase described above can be securely maintained by dint of the magnetic force of permanent magnet block **29**.

Moreover, during the phase shift described above, torque amplifier **5** can amplify the rotary operating force obtained by switching the generated magnetic fields. Thus, the magnetic force generated at first electromagnetic coil **33**A and second electromagnetic coil **33**B can be comparatively small.

In addition, controlling the stop position of permanent magnet block **29** relative to yoke block **30** can freely vary the rotary phase between the crank shaft (not shown) and cam shaft **1**, whether or not the rotary phase is at the most lagging angle or the most leading angle.

According to the first embodiment, torque amplifier **5** has such a constitution that movable member **17** can be engageably guided by inner walls of radial slot **8** and spiral slot **24** which intersect continuously with the direction of lever **9** and intersect substantially orthogonally with each other. Thus, even when a disturbance such as reversed torque which may be caused by the force of the valve spring and/or profile of the drive cam is inputted to movable member **17** by way of lever **9** and link **14**, the inner walls of radial slot **8** and spiral slot **24** can securely absorb load of the disturbance. As a result, rotary phase variation attributable to the input of the disturbance of the reversed torque can be prevented, and decrease in operation response during phase variation can be prevented.

Moreover, according to the first embodiment, movable member **17** constituting torque amplifier **5** is so guided and engaged as to roll relative to radial slot **8** and spiral slot **24** by way of respective first ball **18** and second ball **20**. The rolling of movable member **17** can decrease operation resistance to a great extent during phase shift, to thereby decrease power consumption of first electromagnetic coil **33**A and second electromagnetic coil **33**B.

Each of first electromagnetic coil **33**A and second electromagnetic coil **33**B of electromagnetic coil block **32** has a minimum width. According to the first embodiment, however, electromagnetic coil block **32** is disposed on a first axial side (left in FIG. **1**) of yoke block **30** while permanent magnet block **29** is disposed on a second side (opposite to the first axial side) of yoke block **30**, in addition, first electromagnetic coil **33**A and second electromagnetic coil **33**B can be radially disposed in electromagnetic block **32**. With the dispositions described above, rotary force generator **4** can be shortened axially, to thereby reduce overall size of the rotary phase controller (valve timing controller).

As is seen in FIGS. **13**A and **13**B (also referred to coolectively as FIG. **13**), there is provided a rotary phase controller (valve timing controller), according to a second embodiment of the present invention.

The rotary phase controller according to the second embodiment has a constitution that is different in coil yoke from the first embodiment. More specifically, a coil yoke **146** according to the second embodiment is different from coil yoke **46** according to the first embodiment. Other parts and sections according to the second embodiment are substantially the same as those according to the first embodiment.

Each of first electromagnetic coil **33**A and second magnetic coil **33**B according to the second embodiment is equipped with coil yoke **146** that induces the magnetic flux (generated at coil body **43**) to yoke block **30**. Coil yoke **146** is constituted of a main yoke **60** (coil yoke body) and a pair of sub-yokes **61**. Main yoke **60** has a half cross section shaped substantially into an alphabetical U, and surrounds substantially entire periphery of coil body **43**. The pair of sub-yokes **61** are press fitted to respective open ends of the alphabetical U of main yoke **60**.

Hereinabove, “half cross section” means FIG. **13** shows only upper part of main yoke **60**, leaving lower part of main yoke **60** not shown. This definition of “half cross section” also applies to descriptions hereinafter.

Sub-yoke **61** is annular, and has a half cross section shaped substantially into an alphabetical L as is seen in an enlarged part of FIG. **13**. The alphabetical L of sub-yoke **61** has a first side (horizontal in FIG. **13**) constituted of a cylindrical wall **61***a* and a second side (vertical in FIG. **1**) constituted of a bent piece **61***b*. Bent piece **61***b* is monolithic with a first end (right in FIG. **13**) of cylindrical wall **61***a* in such a manner as to form a flange. Sub-yoke **61** is thinner than main yoke **60**. Cylindrical wall **61***a* is press fitted into an annular cutout **60***a* of main yoke **60**. Thus, according to the second embodiment, an end face (of main yoke **60**) and the bent **61***b* (of sub-yoke **61**) constitute a magnetic input-output end (of coil yoke **146**) which opposes each of first pole tooth ring **37** and second pole tooth ring **38** of yoke block **30**. In FIG. **13**, there is defined a thickness T1 of main yoke **60**, and a thickness T2 of sub-yoke **61**.

An inner peripheral wall of main yoke **60** is thicker than an outer peripheral wall of main yoke **60**, to thereby minimize difference in cross section between the inner peripheral wall and the outer peripheral wall. Thus, the overall magnetic resistance can be maintained small from the inner peripheral wall to the outer peripheral wall of main yoke **60**.

According to the second embodiment, the magnetic input-output end of coil yoke **146** is constituted of the end face (of main yoke **60**) and bent piece **61***b* (of sub-yoke **61**). Thus, the area (of the magnetic input-output end) opposing first pole tooth ring **37** and second pole tooth ring **38** can be formed larger than the cross section of main yoke **60**. Thereby, decreasing the magnetic resistance at air gap AG does not involve enlargement of main yoke **60**.

Being a part of sub-yoke **61** which is not monolithic with main yoke **60**, bent piece **61***b* can be formed sufficiently thinner than main yoke **60**. Thus, bending bent piece **61***b* of sub-yoke **61** during molding is of ease, and overall axial length of coil yoke **146** can be reduced. Moreover, main yoke **60** can be formed sufficiently thick (great in cross section) irrespective of thickness of bent piece **61***b*. Thereby, the magnetic resistance of main yoke **60** can be sufficiently small.

Moreover, according to the second embodiment, due to the following constitutions sub-yoke **61** can be securely fixed to main yoke **60** whether or not the entire thickness of sub-yoke **61** is reduced:

1. Annular sub-yoke **61** is so formed as to have the half cross section shaped substantially into the alphabetical L.
2. Cylindrical wall **61***a* constituting the first side (horizontal in FIG. **13**) of the alphabetical L is press fitted into main yoke **60**.

Bent piece **61***b* disposed radially outside (extending radially inward in FIG. **13**) has a first area opposing first pole tooth ring **37**, while bent piece **61***b* disposed radially inside (extending radially outward in FIG. **13**) has a second area opposing second pole tooth ring **38**. Bent piece **61***b* disposed radially inside is preferred longer than bent piece **61***b* disposed radially outside, for the following cause:

In this case, difference between the first area and the second area described above can be decreased. Thus, the magnetic resistance of the entire part including air gap AG can be further reduced.

According to the second embodiment described above, the coil yoke body (main yoke **60**) of coil yoke **146** is not monolithic with bent piece **61***b* of sub-yoke **61**, for ease of production. The second embodiment is, however, not limited to the one described above. The coil yoke body (main yoke **60**) of coil yoke **146** can be monolithic with bent piece **61***b* of sub-yoke **61**.

As is seen in FIGS. **14** and **15**, there is provided a rotary phase controller (valve timing controller), according to a third embodiment of the present invention.

Like the first embodiment, the rotary phase controller according to the third embodiment is applied to the valve timing controller of the internal combustion engine. The valve timing controller according to the third embodiment, however, has a constitution that is different in rotary force generator. More specifically, a rotary force generator **104** according to the third embodiment is different from rotary force generator **4** according to the first embodiment. Other parts and sections according to the third embodiment are substantially the same as those according to the first embodiment. Therefore, described hereinafter are the differences only from the first embodiment. Parts and sections common to those of the first embodiment are denoted by the same numerals, and repeated descriptions are to be omitted.

Like rotary force generator **4** according to the first embodiment, rotary force generator **104** according to the third embodiment is constituted of a permanent magnet block **129**, a yoke block **130** and an electromagnetic coil block **132** which are a little different in constitution, respectively, from permanent magnet block **29**, yoke block **30** and electromagnetic coil block **32** according to the first embodiment.

As is seen in FIG. **15**, permanent magnet block **129** has an overall constitution which is shaped substantially into a cylinder. A plurality of magnetic poles extending axially are disposed in such a manner that different magnetic poles alternate circumferentially. More specifically in FIG. **15**, there are shown a plurality of north-pole magnetic surfaces **136***n* and a plurality of south-pole magnetic surfaces **136***s*.

Yoke block **130** is constituted of a first yoke **139**A and a second yoke **139**B each of which has a pair of a first pole tooth ring **137** and a second pole tooth ring **138**. The entire part of yoke block **130** is shaped substantially into a cylinder having a thin wall. First pole tooth ring **137** and second pole tooth ring **138** of each of first yoke **139**A and second yoke **139**B are made of metal having high permeability. Moreover, first pole tooth ring **137** has a first base section **137***a* shaped substantially into a cylindrical ring, and a plurality of first pole teeth **137***b* shaped substantially into trapezium and extending axially from first base section **137***a*; while second pole tooth ring **138** has a second base section **138***a* shaped substantially into a cylindrical ring, and a plurality of second pole teeth **138***b* shaped substantially into trapezium and extending axially from second base section **138***a*. First pole tooth ring **137** and second pole tooth ring **138** are arranged axially in such a manner that first pole teeth **137***b* and second pole teeth **138***b* can be disposed circumferentially at regular angular intervals. Moreover, addenda of first pole teeth **137***b* and second pole teeth **138***b* extend axially in such a manner as to direct, respectively, toward second base section **138***a* (of the mating second pole tooth ring **138**) and first base section **137***a* (of the mating first pole tooth ring **137**).

First yoke **139**A and second yoke **139**B are arranged axially. Resin material **40** (insulator) is filled between first pole tooth ring **137** and second pole tooth ring **138** so as to fill all gaps between first pole tooth ring **137** and second pole tooth ring **138**. First base section **137***a* and second base section **138***a* are disposed radially outside, while first pole teeth **137***b* and second pole teeth **138***b* are disposed radially inside. For allowing disposition described above, a connection is bent between first pole tooth **137***b* and first base section **137***a*, while a connection is bent between second pole tooth **138***b* and second base section **138***a*. Yoke block **130** is spaced apart from permanent magnet block **129**, and disposed radially outside permanent magnet block **129**. Each of first pole tooth **137***b* and second pole tooth **138***b* is so disposed as to face north-pole magnetic surface **136***n* and south-pole magnetic surface **136***s* of permanent magnet block **129**.

On the other hand, electromagnetic coil block **132** has an annular housing **141** which is open radially inward and fixed to an inner periphery of valve timing control cover **31**. A first electromagnetic coil **133**A and a second electromagnetic coil **133**B are arranged axially in housing **141**. Moreover, each of first electromagnetic coil **133**A and second electromagnetic coil **133**B has a first magnetic input-output end **144** and a second magnetic input-output end **145** which are so arranged to direct radially inward. Yoke block **130** is disposed radially inside electromagnetic coil block **132**, in such a manner that first base section **137***a* (of first pole tooth ring **137** of each of first yoke **139**A and second yoke **139**B) and second base section **138***a* (of second pole tooth ring **138** of each of first yoke **139**A and second yoke **139**B) face, respectively, first magnetic input-output end **144** and second magnetic input-output end **145** by way of air gap AG.

According to the first embodiment, permanent magnet block **29** is fixed to middle rotor **23**, while yoke block **30** is fixed to hold ring **12** which is coupled to cam shaft **1**.

Contrary to the above, in the valve timing controller according to the third embodiment, permanent magnet block **129** is fixed to drive plate **3** by way of a first bracket **50**, while yoke block **130** is fixed to a middle rotor **123** by way of a second bracket **51**. According to the third embodiment, a rotary operating force generated at rotary force generator **104** can be inputted to torque amplifier **5** by way of middle rotor **123**, and an amplified force (which is amplified with torque amplifier **5**) can be sent to drive plate **3** and cam shaft **1**; although permanent magnet block **129** and yoke block **130** according to the third embodiment are fixed to members different from those of their counterparts (namely, permanent magnet block **29** and yoke block **30**) according to the first embodiment. According to the third embodiment, a radial ball bearing **52** can support middle rotor **123** to a lever shaft **110** which is monolithic with a hold ring.

Rotary force generator **104** of the valve timing controller according to the third embodiment has fundamental functions substantially the same as those of rotary force generator **4** according to the first embodiment. Thus, according to the third embodiment, switching at predetermined patterns the magnetic field which is generated at electromagnetic coil block **132** can vary freely the rotary phase of the crank shaft (not shown) relative to cam shaft **1**, like the first embodiment. Moreover, like the first embodiment, radial slot **8**, spiral slot **24**, movable member **17**, link **14** and the like of torque amplifier **5** are so constituted as to receive the disturbance which may be caused by the reversed torque and the like.

The valve timing controller according to the third embodiment is, however, so constituted that permanent magnet block **129** is disposed radially inside yoke block **130** while electromagnetic coil block **132** is disposed radially outside yoke block **130**. The above constitution can maintain preferable torque balance when yoke block **130** and permanent magnet block **129** make revolution relative to each other.

More specifically, the relative revolution between yoke block **130** and permanent magnet block **129** can sequentially vary the magnetic pole of first pole teeth **137***b* and the magnetic pole of second pole teeth **138***b*, to thereby shift circumferentially magnetic attraction section and magnetic repulsion section between permanent magnet block **129** and yoke block **130**. Hereinabove, the magnetic attraction and repulsion sections (namely, first pole teeth **137***b*, second pole teeth **138***b*, north-pole magnetic surface **136***n* and south-pole magnetic surface **136***s*) are all equidistant from a rotary center. Thus, variation in drive torque which may be caused by step motions can be extremely small, to thereby smoothen rotary operation of the rotary phase controller.

Although the present invention has been described above by reference to three embodiments, the present invention is not limited to the three embodiments described above. Modifications and variations of the three embodiments described above will occur to those skilled in the art, in light of the above teachings.

More specifically, not only to the valve timing controller of the internal combustion engine, the phase controller can be applied to other power transmission systems.

The entire contents of basic Japanese Patent Application No. P2001-184301 (filed on Jun. 19, 2001 in Japan) of which priority is claimed and basic Japanese Patent Application No. P2001-323941 (filed on Oct. 22, 2001 in Japan) are incorporated herein by reference.

The scope of the present invention is defined with reference to the following claims.

What is claimed is:

1. A rotary phase controller varying rotary phase of a drive rotor and a follower rotor through a relative rotary operation between the drive rotor which is rotatably driven and the follower rotor which receives a power from the drive rotor, the rotary phase controller comprising:

a permanent magnet block disposed on one of the drive rotor's side and the follower rotor's side, the permanent magnet block having a constitution in which different magnetic pole surfaces of a permanent magnet are alternately arranged circumferentially;

a yoke block disposed as a whole on the other of the drive rotor's side and the follower rotor's side, the yoke block including a plurality of yokes including a first yoke and a second yoke, each of the plurality of the yokes including:

a first pole tooth ring formed with a plurality of first pole teeth which oppose the magnetic pole surfaces of the permanent magnet block, and

a second pole tooth ring formed with a plurality of second pole teeth which oppose the magnetic pole surfaces of the permanent magnet block,

the first pole teeth and the second pole teeth being alternately disposed circumferentially, the first yoke and the second yoke being assembled such that the first pole teeth of the first yoke are shifted by a predetermined pitch circumferentially from the second pole teeth of the second yoke;

an electromagnetic coil block fixed to an irrotational member, the electromagnetic coil block including a plurality of electromagnetic coils including a first electromagnetic coil and a second electromagnetic coil corresponding respectively to the first yoke and the second yoke of the yoke block, each of the first electromagnetic coil and the second electromagnetic coil having a magnetic input-output end opposing, by way of an air gap, the first pole tooth ring and the second pole tooth ring of the respective first yoke and second yoke, the yoke block and the permanent magnet block making a revolution relative to each other by varying at a predetermined pattern a magnetic field which is generated at the plurality of the electromagnetic coils.

2. The rotary phase controller as claimed in claim **1**, wherein at least one of the yoke block and the permanent magnet block is connected to one of the drive rotor and the follower rotor by way of a torque amplifier.

3. The rotary phase controller as claimed in claim **2**, wherein

the torque amplifier comprises:

a radial guide disposed on one of the drive rotor's side and the follower rotor's side,

a movable member engageably supported to the radial guide in such a manner as to displace radially, the movable member connecting by way of a link to a portion which is spaced apart at a predetermined distance from a rotary center of the other of the drive rotor and the follower rotor,

a middle rotor having a spiral guide which engageably guides the movable member, the middle rotor being disposed in such a manner as to revolve relative to the drive rotor and the follower rotor, and

the middle rotor is rotatably integrated with one of the yoke block and the permanent magnet block.

4. The rotary phase controller as claimed in claim **3**, wherein at least one of a first pair of the movable member and the spiral guide and a second pair of the movable member and the radial guide are rollably engaged by way of a ball.

5. The rotary phase controller as claimed in claim **1**, wherein an insulator is filled between the adjacent yokes of the yoke block, and between the first pole tooth ring and the second pole tooth ring of each of the yokes.

6. The rotary phase controller as claimed in claim **5**, wherein

the first pole tooth ring has a first base section shaped substantially into a ring, and the second pole tooth ring has a second base section shaped substantially into a ring, and

the first pole tooth ring and the second pole tooth ring are so bent that the respective first base section and second base section are disposed on the electromagnetic coil block's side while the respective first pole teeth and second pole teeth are disposed on the permanent magnet block's side.

7. The rotary phase controller as claimed in claim **1**, wherein

each of the first electromagnetic coil and the second electromagnetic coil of the electromagnetic coil block includes a coil yoke,

the coil yoke surrounds a coil body, and has a cross section shaped substantially into an alphabetical U and having an opening toward the yoke block's side,

the opening of the coil yoke has an end which is formed with a bent piece,

the bent piece extends in such a manner as to oppose at least one of the first pole tooth ring and the second pole tooth ring of the yoke block, and constitutes the magnetic input-output end, and

the bent piece has a thickness which is smaller than a thickness of a coil yoke body.

8. The rotary phase controller as claimed in claim **7**, wherein

the coil yoke includes:

a main yoke constituting the coil yoke body having a cross section shaped substantially into the alphabetical U, and

a sub-yoke having the bent piece, and mounted to an open end of the main yoke.

9. The rotary phase controller as claimed in claim **8**, wherein the sub-yoke is shaped substantially into an annular ring having a cross section shaped substantially into an alphabetical L.

10. The rotary phase controller as claimed in claim **7**, wherein the coil yoke body has an outer peripheral wall and an inner peripheral wall which is thicker than the outer peripheral wall.

11. The rotary phase controller as claimed in claim **7**, wherein the bent piece disposed radially inside extends longer than the bent piece disposed radially outside.

12. The rotary phase controller as claimed in claim **1**, wherein the permanent magnet block has a surface which is substantially orthogonal to a direction of axis of the rotary phase controller and which is circumferentially formed with a plurality of the magnetic pole surfaces extending radially,

the yoke block is so constituted that the pole tooth rings of all the yokes are arranged radially in a form of a disk, and that the first pole teeth of the first pole tooth ring of each of the yokes extend radially to direct toward the corresponding second base section while the second pole teeth of the second pole tooth ring of each of the yokes extend radially to direct toward the corresponding first base section, and

the electromagnetic coil block is so constituted that the first electromagnetic coil and the second electromagnetic coil are arranged radially to oppose the corresponding respective first yoke and second yoke of the yoke block by way of the air gap which is formed axially.

13. The rotary phase controller as claimed in claim **1**, wherein

the permanent magnet block has a surface which is substantially cylindrical and which is circumferentially formed with a plurality of the magnetic pole surfaces extending in a direction of axis of the rotary phase controller,

the yoke block is so constituted that the pole tooth rings of all the yokes are arranged axially in a form of a cylinder, and that the first pole teeth of the first pole tooth ring of each of the yokes extend axially to direct toward the corresponding second base section while the second pole teeth of the second pole tooth ring of each of the yokes extend axially to direct toward the corresponding first base section, and

the electromagnetic coil block is so constituted that the first electromagnetic coil and the second electromagnetic coil are arranged axially to oppose the corresponding respective first yoke and second yoke of the yoke block by way of the air gap which is formed radially.

14. The rotary phase controller as claimed in claim **1**, wherein

the drive rotor connects to a crank shaft of an internal combustion engine,

the follower rotor connects to a cam shaft of the internal combustion engine, and

the drive rotor and the follower rotor are so varied in rotary phase as to vary valve's open-close timing of the internal combustion engine.

15. A valve timing controller of an internal combustion engine varying rotary phase of a crank shaft and a cam shaft through a relative rotary operation between a drive rotor which is driven by the crank shaft and a follower rotor which is one of the cam shaft and a member coupled to the cam shaft, the valve timing controller comprising:

a permanent magnet block disposed on one of the drive rotor's side and the follower rotor's side, the permanent magnet block having a constitution in which different magnetic pole surfaces of a permanent magnet are alternately arranged circumferentially;

a yoke block disposed as a whole on the other of the drive rotor's side and the follower rotor's side, the yoke block including a plurality of yokes including a first yoke and a second yoke, each of the plurality of the yokes including:

a first pole tooth ring formed with a plurality of first pole teeth which oppose the magnetic pole surfaces of the permanent magnet block, and

a second pole tooth ring formed with a plurality of second pole teeth which oppose the magnetic pole surfaces of the permanent magnet block,

the first pole teeth and the second pole teeth being alternately disposed circumferentially, the first yoke and the second yoke being assembled such that the first pole teeth of the first yoke are shifted by a predetermined pitch circumferentially from the second pole teeth of the second yoke;

an electromagnetic coil block fixed to an irrotational member, the electromagnetic coil block including a plurality of electromagnetic coils including a first electromagnetic coil and a second electromagnetic coil corresponding respectively to the first yoke and the second yoke of the yoke block, each of the first electromagnetic coil and the second electromagnetic coil having a magnetic input-output end opposing, by way of an air gap, the first pole tooth ring and the second pole tooth ring of the respective first yoke and second yoke, the yoke block and the permanent magnet block making a revolution relative to each other by varying at a predetermined pattern a magnetic field which is generated at the plurality of the electromagnetic coils.

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